

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 101

No. 3

1941 MARCH 14

ANNUAL GENERAL MEETING

Professor H. C. Plummer, President, in the Chair.

The Minutes of the preceding Annual General Meeting were read and confirmed.

The following candidates were proposed for election as Fellows of the Society, the name of the proposer from personal knowledge being appended:—

Archibald Brown, M.A., Trinity College, Cambridge (proposed by Sir A. S. Eddington);

Cecil Charles Hilton Rowe, F.R.S.A., F.I.L., c/o Bank of England, Whitchurch, Hants (proposed by F. M. Holborn); and

Alan J. Skinner, B.A., 64 Cambridge Road, Anerley, London, S.E. 20 (proposed by A. D. Thackeray).

Before proceeding to give his Address on "The Development of the Vertical Telescope" (see p. 165), the President made a short statement on the action taken by the Officers and Council during the previous year, in virtue of the special powers given to Council under bye-law 87. He said:

It is now thirteen months since the operation of our bye-laws was suspended by a vote at the last Annual General Meeting. By taking this course the whole body of regulations can be restored intact at the earliest fitting opportunity. The alternative would have been to make alterations piecemeal, and it was difficult if not impossible to foresee what the needs of the future would be. Therefore the bolder course was recommended and you endorsed it.

This has thrown a greater responsibility on Council and on the officers of the Society. Down to November the only innovation was in the hour of the ordinary meetings. Then it was decided that there should be no meetings in December and January, and that the Annual General Meeting should be held in March instead of February. This decision was due to the probable inconvenience of railway travel coupled with the early black-out. The question of an ordinary meeting in February was left open. A Council meeting was held in that month, on the usual day and in the usual place. But the event showed that it would have been impossible to hold an ordinary meeting on the same

day without inconvenience. If it be thought that Council and ordinary meetings should be held on separate days, the difficulty experienced in bringing together a small officers' meeting during the days of winter suggests that the difficulty would have been too great for success. It seemed better to look for compensation to the longer days of summer, when it is hoped to hold meetings after our usual close in June.

One consequence of our failure to hold meetings must be reported. Candidates proposed for election in November were definitely elected by Council in February. This exceptional course was taken because otherwise the candidates would have been required to wait four months for confirmation at a meeting of Fellows. It will be followed only in exceptional circumstances, for it is an undoubted infringement of the rights of Fellows according to the bye-laws now in abeyance.

For your information, and not because any constitutional question is involved, it may be mentioned that the opportunity has been taken to bring the volume of the *Monthly Notices* into coincidence with the calendar year. Thus Vol. 101 will be published in the year 1941. Owing to the serious interruption of observatory work it has been decided not to include the usual Observatory Reports in the Annual Report for the past year.

After the delivery of the President's Address, visitors were requested to withdraw, and the Society proceeded to the formal business of the Meeting.

The Report of the Auditors was read (see p. 123).

The Annual Report of the Council was partly read.

A vote of thanks to the Auditors of the Treasurer's Accounts for 1940 was proposed and carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Auditors and the President's Address.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 173.

The thanks of the Society were given to the retiring President, Vice-President, and Secretary (Dr. Atkinson) and other retiring members of Council.

The thanks of the Society were also given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE
HUNDRED AND TWENTY-FIRST
ANNUAL GENERAL MEETING OF THE SOCIETY

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Honorary Member	Fellows		Associates	Total
				Compounders	Annual Subscribers		
1939 December 31	1	4	1	185	660	50	901
Since elected... ..	...	+ 1	...	+ 1	+ 25	...	...
Deceased, 1940	...	...	...	- 7	- 6	- 1	...
Deceased before 1940, death not notified	...	...	...	- 1	- 3	...	...
Resigned	...	...	...	...	- 12	...	...
Since compounded	...	...	...	+ 4	- 4	...	...
Non-active Fellows:							
(a) In enemy or enemy-occupied countries	...	...	...	...	- 15	...	...
(b) On Service (Byelaw 26A) ...	...	...	...	...	- 10	...	...
Removed from list	...	...	...	...	- 10	...	...
1940 December 31	1	5	1	182	625	49	863

(Seven Associates are also Fellows, and are therefore counted
twice in the above table.)

MR. REYNOLDS'S ACCOUNTS AS TREASURER OF THE ROYAL

Cash

RECEIVED

	£	s.	d.	£	s.	d.
Balances, 1940 January 1—						
In hand of Assistant Secretary on Petty Cash Account				4	7	9
At Bankers', on Current Account	£298	5	11			
Less Cheque not yet debited	8	0	0			
				290	5	11
Cheque not yet credited				0	7	0
At Bankers', on "B" Account (Cash Balance of Spencer Bequest)... ..				163	18	11
At Bankers', on "C" Account—						
Trust Funds	£172	6	6			
Sales of Duplicate Books	66	19	6			
Goodridge Bequest	3	8	8			
				242	14	8
Dividends on Investments (as per schedule)				708	7	4
Interest on Savings Banks Deposits				12	19	4
Income Tax refunded, 1939 April–1940 April				196	15	3
Sales of Publications—						
For 1940	£213	0	2			
Due in 1939	9	13	8			
1941 in advance	6	15	6			
				229	9	4
Reprints—						
For 1940	£56	16	7			
Due in 1939	10	11	0			
				67	7	7
Sales of Photographs				6	16	6
Miscellaneous Receipts—						
Donation to General Funds	£10	0	0			
London Mathematical Society, Expenses of Meetings	10	0	0			
Assistant Secretary and Clerk, Pension Contributions	19	5	0			
Use of Telephone	0	5	8			
Postage repaid... ..	1	13	4			
Excess on Subscriptions	0	15	6			
				41	19	6
Porter's Pension Contributions						
						1263 14 10
Received on account of Subscriptions—						
521½ Annual Contributions, 1940				1095	3	0
1 Special Contribution, 1940, at 4 guineas				4	4	0
3 Institutional Membership Fees				6	6	0
15 Annual Contributions, 1941, in advance				31	10	0
1 ditto, 1942, in advance				2	2	0
24 Admission Fees, 1940				50	8	0
23 First Contributions, 1940, at 2 guineas				48	6	0
Arrears paid off—						
7 for 1938	£14	14	0			
37 for 1939	77	14	0			
				92	8	0
Compositions—						
1 Initial				31	10	0
4 Reduced				46	4	0
						77 14 0
Redemption of New Zealand 3½% Loan, 1940						2000 0 0
Proceeds of Sale of £409, 17s. 11d. Conversion Loan 4½%						420 2 2
"B" Account—						
Legacy from the late A. Stanley Williams (final instalment)				152	10	0
Ditto, 1st instalment (1939) transferred from General Account				150	0	0
Proceeds of Sale of £300 War Loan 3½% (Spencer Bequest)				297	0	0
						599 10 0
"C" Account—						
Dividends (as per schedule)				165	5	6
Income Tax refunded, 1939 April–1940 April				27	18	8
						193 4 2
Examined and found correct.						£6599 6 5

(Signed) M. G. ADAM
D. S. EVANS

ASTRONOMICAL SOCIETY, FROM 1940 JANUARY 1 TO DECEMBER 31

Account

	PAID			£	s.	d.	£	s.	d.
Assistant Secretary: Salary	£267	11	3						
Inland Revenue, Income Tax on ditto, 1 month	2	8	9						
Clerk: Balance of Salary				270	0	0			
Rent of Assistant Secretary's Room at Oxford				14	10	0			
Pension Premiums for Assistant Secretary and Clerk				104	0	0			
Porter and Wife: Wages				57	15	0			
Health and Unemployment Insurance				157	12	6			
				7	11	8			
Insurance, Taxes and Telephone							611	9	2
Postage and Packing—							45	17	7
<i>Monthly Notices</i> , etc.				127	19	5			
Office Postages				53	9	2			
							181	8	7
Printing, etc.—									
<i>Monthly Notices</i> (Vol. 100)				855	17	6			
<i>Geophysical Supplements</i> (Vol. 4, Nos. 8, 9)				124	6	8			
<i>Occasional Notes</i> (Nos. 7, 8)				34	12	0			
Reprints				107	9	6			
Miscellaneous				71	14	9			
Photo-engraving (<i>M.N.</i> , <i>G.S.</i> and <i>O.N.</i>)				61	14	2			
							1255	14	7
Stationery and Office Expenses				17	12	9			
Gold Medal (including engraving)				15	9	0			
A.R.P. Expenditure				12	13	0			
Storage of Stanley Williams Telescopes				5	19	6			
Expenditure from Potter Fund (Library)				0	12	3			
Heating and Lighting				93	6	0			
Fittings and Repairs				13	12	8			
House Expenses and Laundry				25	1	0			
Accountant's Fee				5	5	0			
Subscription to Committee on Library Co-operation				1	1	0			
Authorised Travelling Expenses				31	7	5			
Expenses of R.A.S. Meetings and Committees				12	18	5			
Expenses of Geophysical Meeting				1	7	0			
Expenses of London Mathematical Society Meetings				3	0	5			
Miscellaneous Expenditure				8	1	10			
Clerical Assistance				6	8	0			
Bank Charges and Cheque Books... ..				2	11	1			
Purchase of Book from Sales of Duplicate Books Fund				3	9	9			
							259	16	1
							2354	6	0
Porter's Pension Premium, 1940 August 1–1941 July 31							26	0	0
Purchase of £1431, 4s. 11d. War Loan 3½% Stock							1420	2	2
Transfer to "B" Account of A. S. Williams Legacy received in 1939							150	0	0
Grant from Spencer Bequest							50	0	0
Expenditure on Trust Accounts—									
Turnor and Horrocks Fund (Library)				11	2	2			
Harry Watson Fund (Library)				8	11	9			
							19	13	11
Balances, 1940 December 31—									
In hand of Assistant Secretary on Petty Cash Account				11	18	5			
At Westminster Bank, on Current Account				428	2	6			
At Westminster Bank, on "B" Account—									
Cash Balance of Spencer Bequest	£410	18	11						
A. S. Williams Legacy	302	10	0						
				713	8	11			
At Westminster Bank, on "C" Account—									
Trust Funds	£344	2	5						
Sales of Duplicate Books Fund	63	9	9						
Goodridge Bequest	5	3	0						
				412	15	2			
At Post Office Savings Bank	£507	5	10						
At London Savings Bank	505	13	6						
				1012	19	4			
							2579	4	4
							£6599	6	5

MR. REYNOLDS'S ACCOUNTS AS TREASURER OF THE ROYAL

										Revenue					
										£	s.	d.	£	s.	d.
To	General	Expenditure	as	per	Cash	Account	...	...	...	2354	6	0			
„	Porter's	Pension	Premium,	1940	August	1	to	December	31, at 10s.						
	a	week	...	...	...	...	...	...	...	11	0	0			
„	Ditto,	January	1	to	July	31,	paid	in	1939 and now matured	15	0	0			
„	Reserve	for	Accounts	due	but	not	presented	...	...	40	0	0			
										2420	6	0			
Less	Reserve	for	Accounts	due	1939,	now	written	back	...	125	0	0	2295	6	0
„	Amount	transferred	to	Composition	Fees	Reserve	Fund,	1940	...				77	14	0
„	Special	Repairs	and	Maintenance	Account:	Annual	Reserve,	as	per						
	Balance	Sheet	...	...	...	...	...	...	...				56	11	1
„	26	Annual	Contributions	in	Arrears	(1938-39)	written	off	...	54	12	0			
„	14	Annual	Contributions,	1940,	written	off	as	per	contra	29	8	0			
													84	0	0
„	Due	for	Publications	and	Reprints	1937-39,	written	off	...				5	4	9
„	Excess	of	Revenue	over	Expenditure,	1940	...	...	...				365	0	6
										£2883 16 4					

Examined and found correct.

(Signed) M. G. ADAM

D. S. EVANS

1941 January 22

Account, 1940

	£	s.	d.	£	s.	d.
By 521½ Annual Contributions, 1940	1095	3	0			
„ 1 ditto, paid in 1938 and now matured	2	2	0			
„ 7 ditto, paid in 1939 and now matured	14	14	0			
„ 1 Special Contribution, 1940, at 4 guineas	4	4	0			
„ 3 Institutional Membership Fees	6	6	0			
„ 1 ditto, paid in 1939 and now matured	2	2	0			
„ 1 ditto, outstanding	2	2	0			
„ 84½ Annual Contributions, 1940, outstanding	177	9	0			
„ 14 Ditto, due but unpaid, in respect of Fellows died, resigned, or names removed, and written off per contra	29	8	0			
				1333	10	0
<i>Suspense Account—</i>						
15 Annual Contributions due but unobtainable under war conditions	£31	10	0			
10 ditto waived under Byelaw 26A	21	0	0			
	£52	10	0			
„ 24 Admission Fees	50	8	0			
„ 2 ditto, outstanding	4	4	0			
26				54	12	0
„ 23 First Contributions at 2 guineas	48	6	0			
„ 1 ditto, outstanding, at 2 guineas	2	2	0			
„ 1 ditto, outstanding, at 1 guinea	1	1	0			
25				51	9	0
„ 1 Composition Fee (Initial)	31	10	0			
„ 4 ditto, reduced	46	4	0			
5				77	14	0
„ 6% of Composition Fees Reserve Fund, as per Balance Sheet, trans- ferred to Current Revenue				47	9	0
„ Sundry Debtors, 1940	18	1	9			
Less written off, considered irrecoverable under war conditions	1	18	9			
				16	3	0
„ Dividends and Income Tax refund	918	1	11			
„ Sales of Publications, Photographs and Miscellaneous Receipts, as per Cash Account	345	12	11			
	1263	14	10			
Less { Payments due 1939	£20	4	8			
„ Advance payments for Publications, 1941	6	15	6			
„ Income Tax (General Fund) 1939 April- December, refunded in 1940	108	10	6			
	135	10	8			
				1128	4	2
„ Porter's Pension Contributions				13	0	0
„ Payments for Publications, 1940, received in 1939 and now matured	22	12	7			
Less still in credit	1	7	1			
				21	5	6
„ Income Tax (General Fund) deducted at source 1940 April- December, not yet refunded				140	9	8
				£2883	16	4

MR. REYNOLDS'S ACCOUNTS AS TREASURER OF THE ROYAL

Balance Sheet

LIABILITIES						£	s.	d.	£	s.	d.
15 Subscriptions for 1941, paid in 1940	...	...	...	...	...	31	10	0			
1 Subscription for 1941, paid in 1938	...	...	...	...	...	2	2	0			
1 Subscription for 1942, paid in 1940	...	...	...	...	...	2	2	0			
									35	14	0
Sundry Creditors for Accounts due but not presented	...	...							40	0	0
Cash Balances, Trust Funds	...	...	...	...	...	344	2	5			
Cash Balance of Goodridge Bequest	...	...	...	...	...	5	3	0			
									349	5	5
Trust Funds and Goodridge Bequest (Capital) as per contra	...								4,582	2	7
Income Tax on Trust Funds, 1940 April-December, not yet refunded	...	...	...	...	...				30	0	11
Special Fund (Capital), as per contra	...	...	...	...	...				1,480	2	2
Composition Fees Reserve Fund—											
As at 1939 December 31	...	...	...	...	...	713	2	5			
Received in 1940	...	...	...	...	...	77	14	0			
									790	16	5
Less 6% transferred to Current Revenue	...	...	...			47	9	0			
									743	7	5
Franklin-Adams Charts: as at 1939 December 31	...	...	...						137	18	1
Advance Receipts for Publications, 1940	...	...	...	...	...				6	15	6
Credits still in hand from 1939...	...	...	...	...	...				1	7	1
General Fund—											
As at 1939 December 31	...	...	...	...	...	19,386	10	0			
Deduct Loss on sale of War Stock (Spencer Bequest)	...	...				22	0	1			
						19,364	9	11			
Add Excess on redemption of New Zealand Loan at par	...					429	16	0			
						19,794	5	11			
Deduct Expenditure from Spencer Bequest	...	...	...			50	0	0			
						19,744	5	11			
Add Stanley Williams Bequest (final instalment)	...	...				152	10	0			
						19,896	15	11			
Deduct 9 Subscriptions, 1937-39, taken as assets in 1939 Balance Sheet, now transferred to Suspense Account	...	...				18	18	0			
						19,877	17	11			
Add Excess of Revenue over Expenditure, 1940	...	...				365	0	6			
									20,242	18	5
									<u>£27,649</u>	<u>11</u>	<u>7</u>

Examined and found correct.

(Signed) M. G. ADAM

D. S. EVANS

1941 January 22

ASTRONOMICAL SOCIETY, FROM 1940 JANUARY 1 TO DECEMBER 31

1940 December 31

ASSETS

Sundry Debtors for Subscriptions in Arrears—										£	s.	d.	£	s.	d.
22	for 1939	...	...	...	...	...	...	...	...	46	4	0			
84½	for 1940	...	...	...	...	...	...	...	...	177	9	0			
1	Institutional Membership Fee outstanding	...	...	...	...	...	...	...	...	2	2	0			
													225	15	0
2	Admission Fees outstanding	...	...	...	...	...	...	...	...				4	4	0
2	First Contributions outstanding	...	...	...	...	...	...	...	...				3	3	0
<i>Suspense Account—</i>															
2	Subscriptions, 1937–38, unobtainable under war conditions	...	...	...	...	...	...	...	...	£4	4	0			
5	Subscriptions, 1939, ditto	...	...	...	...	...	...	...	...	10	10	0			
15	Subscriptions, 1940, ditto	...	...	...	...	...	...	...	...	31	10	0			
10	Subscriptions, 1940, waived under Byelaw 26A	...	...	...	...	...	...	...	...	21	0	0			
2	Subscriptions, 1939, ditto	...	...	...	...	...	...	...	...	4	4	0			
										£71	8	0			
Sundry Debtors, 1939													4	0	0
Sundry Debtors, 1940													16	3	0
Investments of General Fund, valued as in 1939 Balance Sheet										19,139	10	11			
Less Redemption of New Zealand Loan										2,000	0	0			
										17,139	10	11			
Add Excess on cost price of Stock										429	16	0			
										17,569	6	11			
Add Purchase of £1007, 9s. War Stock 3½% valued at cost...										1,000	0	0	18,569	6	11
Spencer Bequest—															
As at 1939 December 31										319	0	1			
Less { Sale of £300 War Stock 3½%										£297	0	0			
{ Loss on sale										22	0	1			
										319	0	1			
Investments of Special Fund valued at cost										1,460	0	0			
Less Sale of £419, 17s. 11d. Conversion Loan 4½%, 1940–44										420	2	2			
										1,039	17	10			
Add Excess on cost price of Stock										20	2	2			
										1,060	0	0			
Add Purchase of £423, 15s. 11d. War Stock 3½% valued at cost										420	2	2	1,480	2	2
Investments of Trust Funds and Goodridge Bequest, valued as in 1939 Balance Sheet													4,582	2	7
Income Tax 1940 April–December, deducted at source, not yet refunded—															
General Fund										140	9	8			
Trust Funds										30	0	11			
													170	10	7
Porter's Pension Premium, paid in advance for 1941 January 1–July 31													15	0	0
Sundry Balances—															
In hand of Assistant Secretary on Petty Cash Account										11	18	5			
At Bankers', on Current Account...										428	2	6			
At Post Office and London Savings Banks										1,012	19	4			
At Bankers', on "B" Account										713	8	11			
At Bankers', on "C" Account										412	15	2			
													2,579	4	4
Repairs Suspense Account—															
As at 1939 December 31										56	11	1			
Less Annual Reserve, 1940										56	11	1			
										£27,649	11	7			

INVESTMENTS

As at 1940 December 31

General Fund

- £1250 Metropolitan Consolidated 3 per cent. Stock, 1941.
 £2000 Swansea Corporation 3½ per cent. Stock.
 £2287, 6s. 9d. East Indian Railway 3 per cent. New Debenture Stock.*
 £5125 London, Midland and Scottish Railway 4 per cent. Debenture Stock.*
 £750 London, Midland and Scottish Railway 4 per cent. Preference Stock.*
 £2400 Gas Light and Coke Co. 3 per cent. Consolidated Debenture Stock.*
 £2000 Commercial Gas Co. 3 per cent. Debenture Stock.*
 £496 Consolidated 4 per cent. Stock, 1967.
 £500 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961-91.*
 £1000 Hull Corporation 4½ per cent. Redeemable Stock, 1952-72.
 £1000 Central Electricity Board 4½ per cent. Stock, 1957-82.*
 £700 Birmingham Corporation 3 per cent. Inscribed Stock, 1947.
 £1807, 9s. 0d. War Loan 3½ per cent. Inscribed Stock.
 £500 New South Wales 4 per cent. Stock, 1942-62.*
 £1156, 1s. 5d. Metropolitan Water Board 3 per cent. "B" Stock.*
 £500 National Defence Loan, 1954-58, 3 per cent. Bonds.*

Grove-Hills Special Fund

- £423, 15s. 11d. War Loan 3½ per cent. Inscribed Stock.
 £695, 16s. 0d. Conversion Loan 3½ per cent., 1961.
 £535 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961-91.*

Trust Funds

- £1212, 13s. 3d. East Indian Railway 3 per cent. New Debenture Stock.*
 £542, 18s. 2d. India 3½ per cent. Stock.
 £1004 Consolidated 4 per cent. Stock, 1967.
 £965 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961-91.*
 £540, 10s. 4d. War Loan 3½ per cent. Inscribed Stock.
 £1160, 16s. 3d. War Loan 3½ per cent. Inscribed Stock.

* Taxed at source.

REPORT OF THE AUDITORS FOR THE YEAR 1940

We have examined the Treasurer's accounts of receipts and expenditure, the Revenue Account and the Balance Sheet for the year 1940, and have certified them to be correct. All the investment holdings have been certified by the Bank of England or by the Westminster Bank. There has still been no formal revaluation of the investments of the General Fund, but the Treasurer has estimated their value from Stock Exchange quotations for 1940 December 31 as £19,800, compared with the Balance Sheet figure of £18,569, 6s. 11d.

Since the last Balance Sheet the Society's holding of £2000 New Zealand 3½ per cent. Loan, 1940, has been redeemed at par, with an excess on the original cost of £429, 16s. 0d. Of this, £1000 has been invested in the purchase of £1007, 9s. 0d. of 3½ per cent. War Stock, while the remaining £1000 has been placed on deposit at the Post Office and the London Savings Bank.

The investments of the Spencer Bequest have been wound up by a book transaction whereby £300 of 3½ per cent. War Stock was transferred to the General Fund at 99, the proceeds being placed to "B" Account. From the funds of the Spencer Bequest a grant of £50 has been made to Dr. Steavenson towards the cost of erecting a dome for his 30-inch telescope in the grounds of the University Observatory, Cambridge.

Pursuant to Bye-Law 26A, passed at the Special General Meeting of 1939 November 10, a Suspense Account has been created to cover cases of Fellows who are absent on Active Service, or who are prevented by war conditions from paying their Annual Contributions. This is shown (but not reckoned as an Asset) on the Assets side of the Balance Sheet and comprises a total of 34 Annual Contributions to date. It is gratifying to record that, apart from the Suspense Account, it has so far only been necessary to write off a sum of £1, 18s. 9d. for 1940 as irrecoverable under war conditions, and £5, 4s. 9d. for previous years.

The Revenue Account shows a fall in income from £3157, 17s. 4d. for 1939 to £2883, 16s. 4d. for 1940, but largely as a result of the reduced expenditure on publications there is an excess of revenue over expenditure of £365, 0s. 6d. for 1940.

An amount of £77, 14s. 0d. has been received by way of composition fees during the year, and after the transfer of £47, 9s. 0d. to current revenue the Composition Fees Reserve Fund now stands at £743, 7s. 5d.

There has been no expenditure from the Repairs Suspense Account, which has now been cleared by the appropriation of £56, 11s. 1d. A.R.P. expenditure during the year has been only £12, 13s. 0d. compared with £108, 15s. 5d. during 1939.

A list has been laid on the table containing the names of those Fellows who were still in arrear for sums due on 1940 January 1 with the amount due against each Fellow's name.

The Society's premises have suffered only superficial damage as a result of air raids, and temporary repairs have been carried out. The offices of the Society remain at the University Observatory at Oxford by the continued courtesy of Professor H. H. Plaskett. The Society's early books and manuscripts are still stored partly at Oxford and partly in the strong room at Burlington House.

The Assistant Secretary has furnished us with all the information and explanations we have required, and we are most grateful for her invaluable assistance.

(Signed) M. G. ADAM
DAVID S. EVANS

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift : In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell ; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856) : Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876) : R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877) : C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905) : Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906) : The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922) : The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929-47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922) : Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Lindemann Bequest (1931) : A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936) (*see below*).

The Herbert Spencer Bequest (1936) (*see below*).

The Lindley Bequest (1937) : Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which has been received from the Public Trustee in the form of £1156, 1s. 5d. Metropolitan Water Board 3 per cent. "B" Stock.

THE GROVE-HILLS SPECIAL FUND

In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913, 1s. 11d., of which £1480, 2s. 10d. has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent., £423, 15s. 11d. War Stock 3½ per cent., and £695, 16s. Conversion Loan 3½ per cent. 1961.

THE HERBERT SPENCER BEQUEST

Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The sum of £732, 11s. 9d. was temporarily invested in the purchase of £700 War Loan 3½ per cent. (the dividends being added to the value of the bequest), of which £200 stock was sold in 1938 to meet expenditure, £200 stock was similarly sold in 1939, and the remaining £300 stock in 1940.

Receipts and Expenditure, 1936-1940 Dec. 31

	£	s.	d.		£	s.	d.
1936. First instalment of Bequest received May 7	500	0	0	1936 Dec. Purchase of £500 War Loan 3½ per cent.	531	13	3
1936. Second instalment received July 20	400	0	0	1936. Expenditure as per 1936 Cash Account	276	10	7
1936. Final instalment received Nov. 4	341	0	0	1936 Dec. 31. Cash Balance at Bank, carried forward	432	16	2
	<u>£1241</u>	<u>0</u>	<u>0</u>		<u>£1241</u>	<u>0</u>	<u>0</u>
	£	s.	d.		£	s.	d.
1937 Jan. 1. Cash Balance at Bank, brought forward	432	16	2	1937. Purchase of £200 War Loan 3½ per cent.	200	18	6
1937. Dividends, War Loan 3½ per cent.	21	0	0	1937. Cash expenditure as per 1937 Cash Account	104	7	6
	<u>£453</u>	<u>16</u>	<u>2</u>	1937 Dec. 31. Cash Balance at Bank, carried forward	148	10	2
					<u>£453</u>	<u>16</u>	<u>2</u>
	£	s.	d.		£	s.	d.
1938 Jan. 1. Cash Balance at Bank, brought forward	148	10	2	1938. Purchase of Instruments	124	7	0
1938. Dividends, War Loan 3½ per cent.	24	10	0	1938. Shelving, etc. for Spencer Room	193	5	0
1938. Nov. Sale of £200 War Loan 3½ per cent.	198	11	6	1938 Dec. 31. Cash Balance at Bank, carried forward	53	19	8
	<u>£371</u>	<u>11</u>	<u>8</u>		<u>£371</u>	<u>11</u>	<u>8</u>

	£	s.	d.		£	s.	d.
1939 Jan. 1. Cash Balance at				1939. Purchase of Instruments	85	15	1
Bank, brought forward ...	53	19	8	1939. Carpet, etc., for Spencer			
1939. Dividends, War Loan $3\frac{1}{2}$				Room	11	1	0
per cent.	17	10	0	1939 Dec. 31. Cash Balance at			
1939. Sale of £200 War Loan $3\frac{1}{2}$				Bank, carried forward ...	163	18	11
per cent.	181	11	6				
1939. Refund from Office of							
Works on shelving for Spencer							
Room	7	11	3				
Interest on Deposit Account ...	0	2	7				
	<u>£260</u>	<u>15</u>	<u>0</u>		<u>£260</u>	<u>15</u>	<u>0</u>

	£	s.	d.		£	s.	d.
1940 Jan. 1. Cash Balance at				1940. Grant from Fund ...	50	0	0
Bank, brought forward ...	163	18	11	1940 Dec. 31. Cash Balance at			
1940. Sale of £300 War Loan				Bank, on "B" Account ...	410	18	11
$3\frac{1}{2}$ per cent.	297	0	0				
	<u>£460</u>	<u>18</u>	<u>11</u>		<u>£460</u>	<u>18</u>	<u>11</u>

THE ARCHDEACON POTTER FUND

The late Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a $\frac{3}{88}$ th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 $3\frac{1}{2}$ per cent. War Stock, the cash balance of £17, 15s. 2d. being expended on the library in 1934. The Council resolved to allocate the dividends from this Fund for the purposes of the library.

	£	s.	d.		£	s.	d.
1940 Jan. 1. Balance of Fund ...	33	14	9	1940. Purchase of Books ...	0	12	3
1940. Dividends, War Stock $3\frac{1}{2}$				1940 Dec. 31. Balance of Fund	43	12	6
per cent.	10	10	0				
	<u>£44</u>	<u>4</u>	<u>9</u>		<u>£44</u>	<u>4</u>	<u>9</u>

THE GOODRIDGE BEQUEST

In 1936 Captain J. J. L. Goodridge bequeathed to the Society the sum of £50, free of legacy duty. The Bequest has been invested in £49 War Stock $3\frac{1}{2}$ per cent.

	£	s.	d.		£	s.	d.
1940 Jan. 1. Balance of Fund ...	3	8	8	1940 Dec. 31. Balance of Fund	5	3	0
1940. Dividends, War Stock $3\frac{1}{2}$							
per cent.	1	14	4				
	<u>£5</u>	<u>3</u>	<u>0</u>		<u>£5</u>	<u>3</u>	<u>0</u>

TRUST FUNDS

The Lee and Janson Fund: In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334, 10s. 9d. East Indian Railway 3 per cent. Debenture Stock.

	£	s.	d.
1940 Jan. 1. Balance of Fund ...	43	17	9
1940. Dividends, East Indian Railway	5	19	4
Income Tax, 1939 April-1940 April, refunded	3	10	2
	<u>£53</u>	<u>7</u>	<u>3</u>

	£	s.	d.
1940 Dec. 31. Balance of Fund	53	7	3
	<u>£53</u>	<u>7</u>	<u>3</u>

The Turnor Fund and the Horrocks Memorial Fund: In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464, 18s. East Indian Railway 3 per cent. Debenture Stock. In 1876 the Society received a sum of £38, 15s., the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks: to this the Society added the sum of £55, 15s., and the whole now stands in £103, 6s. East Indian Railway 3 per cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the library.

	£	s.	d.
1940 Jan. 1. Balance of Fund ...	5	3	11
1940. Dividends, East Indian Railway	10	2	4
Income Tax, 1939 April-1940 April, refunded	5	19	4
	<u>£21</u>	<u>5</u>	<u>7</u>

	£	s.	d.
1940. Purchase of Books ...	11	2	2
1940 Dec. 31. Balance of Fund	10	3	5
	<u>£21</u>	<u>5</u>	<u>7</u>

The Harry Watson Memorial Fund: In 1920 Mrs. Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542, 18s. 2d. India 3½ per cent. Stock. In 1923 Mrs. Watson bequeathed a further sum of £958, 17s. to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent. Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

	£	s.	d.
1940 Jan. 1. Balance of Fund	30	4	10
1940. Dividends, India 3½ per cent.	19	0	0
Dividends, Agricultural Mortgage 4½ per cent.	24	19	5
Income Tax, 1939 April-1940 April, refunded	15	3	11
	<u>£89</u>	<u>8</u>	<u>2</u>

	£	s.	d.
1940 Purchase of Books	8	11	9
1940 Dec. 31. Balance of Fund	80	16	5
	<u>£89</u>	<u>8</u>	<u>2</u>

The Hannah Jackson (née Gwilt) Fund: In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309, 18s. 6d. East Indian Railway 3 per cent. Debenture Stock; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	s.	d.		£	s.	d.
1940 Jan. 1. Balance of Fund ...	18	1	0	1940 Dec. 31. Balance of Fund	26	16	8
1940. Dividends, East Indian Railway ...	5	10	5				
Income Tax, 1939 April-1940 April, refunded ...	3	5	3				
	<u>£26</u>	<u>16</u>	<u>8</u>		<u>£26</u>	<u>16</u>	<u>8</u>

The George Darwin Lectureship Fund: In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent. Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1940 Jan. 1. Balance of Fund ...	20	4	9	1940 Dec. 31. Balance of Fund	60	7	11
1940. Dividends, Consolidated 4 per cent. Loan ...	40	3	2				
	<u>£60</u>	<u>7</u>	<u>11</u>		<u>£60</u>	<u>7</u>	<u>11</u>

The A. G. Stillhamer Trust (1937): The late A. G. Stillhamer, Esq., F.R.A.S., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr. Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr. Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The Bequest has been invested in £491, 10s. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1940 Jan. 1. Balance of Fund ...	34	8	0	1940 Dec. 31. Balance of Fund	51	12	0
1940. Dividends, War Stock 3½ per cent. ...	17	4	0				
	<u>£51</u>	<u>12</u>	<u>0</u>		<u>£51</u>	<u>12</u>	<u>0</u>

The E. W. Brown Trust (1939) : Dr. E. W. Brown, of Yale University, who died in 1938, bequeathed to the Society the sum of five thousand dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July, and was invested in £1160, 6s. 3d. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1940 Jan. 1. Cash Balance of				1940 Dec. 31. Balance of Fund	60	18	9
Fund	20	6	3				
1940. Dividends,							
War Stock 3½ per cent. ...	40	12	6				
	<u>£60</u>	<u>18</u>	<u>9</u>		<u>£60</u>	<u>18</u>	<u>9</u>

PUBLICATIONS OF THE SOCIETY

During the past year the Society has published *Monthly Notices*, vol. 100 ; *Geophysical Supplements*, vol. 4, Nos. 8 and 9 ; and *Occasional Notes*, Nos. 7 and 8.

OBITUARY

The Council regret that they have to record the loss by death of the following Fellows and Associate during the past year:—

Fellows: Ernest Cuthbert Atkinson

*George Percy Bailey

†Gustavus Wynne Cook

Edwin Turner Cottingham

George Stuart Forbes

Alfred Fowler

*W. H. St. Quintin Gage

Umes Chandra Ghosh

Lawrence Neville Holden

*Khatheeb Mahmood Hussain

*James Gall Inglis

Augustus Edward Hough Love

Edmund Neville Nevill

Edgar Girard Croker Poole

Sidney Herbert Pope

Henry John Spooner

Evan Gwyn Williams

Associate: †Robert Emden

ERNEST CUTHBERT ATKINSON was a man of many wide scientific and sporting interests to which he applied an inventive ingenuity and love of precision that was to make both science and sport his debtor; in the field of astronomy he will be remembered and honoured for the work he did on precision time-keeping, work which he only took up late in life.

Atkinson was born on 1873 June 22 at Beckenham, Kent; from Merchant Taylors' School he proceeded to St. John's College, Oxford, where he distinguished himself by obtaining "firsts" in mathematics and physics, while at the same time being a prominent figure in rowing and other sporting circles. An early indication of his inventive faculty occurred in this period, when he designed a "Rowing Indicator" giving a continuous record of style and horse-power of an oarsman; to have, in one's college days, an invention exhibited at a Royal Society conversazione must be rare, but to be allowed to demonstrate a rowing machine must surely be rarer, and a powerful indication of the designer's skill. From Oxford he went as assistant master to Rugby where he was Curator of the Temple Observatory, which the boys attended for instruction and demonstration and where the chief observing work was on double stars. After a short period on geodetic work in the Transvaal and Orange River Colonies he returned to England in 1906 to become assistant master at Clifton College, where he stayed until he retired in 1922 to live at Northwood.

Since that time Atkinson was specially interested in the design of precision clocks such as are required for astronomical observatory work. His papers in the *Proceedings of the Physical Society* had undoubtedly a considerable influence on the great progress that has been made in this direction in recent years. Of these papers may be mentioned:

* Died 1939; death not notified until 1940.

† Notice held over till next year.

‡ Notification of death received too late for inclusion of a notice; this will be printed next year.

"The Relation between Rate and Arc for a Free Pendulum"; "On Airy's Disturbance Integrals and Knife-edge Supports for Pendulums"; "The Dissipation of Energy by a Pendulum swinging in Air"; "The Amplitude Deviation of Rate of a Pendulum: a Second Experiment."

He himself designed and constructed several clocks of which at least one, a seconds pendulum, has shown remarkably accurate time-keeping qualities. Throughout this period of his life his interest in clocks and time-keeping was insatiable, and he kept in close contact not only with the observatories at Greenwich, Paris, Hamburg and in the U.S.A., but also with many other amateur enthusiasts, of whom the Society has been proud to number many among its Fellows. In particular it was Atkinson who played a major part in arranging for the late C. O. Bartrum's pendulum being accepted by the Science Museum and erected there.

Throughout his life Atkinson was distinguished by his enthusiastic attitude to whatever branch of science, sport or work that he took up. His record of service in many capacities to rowing, rugby, the Boy Scouts and Boys' Clubs is one of which anyone would be proud. An indication of his undying spirit is given by his immediate offer, on the outbreak of war, to serve in whatever capacity his precise knowledge and experience (he served as musketry instructor during the war of 1914-18) could be utilised. He was not called upon, but he immediately joined the Home Guard on its formation.

He died on 1940 December 3 after a short illness; he never married.

Atkinson was elected a Fellow of the Society on 1904 December 9.

EDWIN TURNER COTTINGHAM was born at Ringstead, near Thrapston, Northants, on 1869 April 9. Leaving school at an early age, he was apprenticed to a tailor in the village; but whilst still in his teens he left the tailor and started to work for a clockmaker Mr. Allen in Thrapston. In this congenial work he made rapid strides, and on Mr. Allen's retirement took over the business. The first clock which he made was the Thrapston church clock, including the whole chiming mechanism. It was his favourite "child," and his last exertion, though ill at the time, was to put it forward for Summer Time in 1940.

In the period between the Riefler clocks and the Shortt clocks Cottingham took a prominent part in the progress of astronomical time-keeping in England. His work was appreciated and encouraged by Dyson and Sampson; and a Cottingham clock had a leading part in the latter's research on "The Measurement of Time to a Thousandth of a Second" (*M.N.*, 78, 592, 1918). In the last war he repaired and timed many Admiralty chronometers, and adapted a Graham regulator from Greenwich for dropping the Time Ball at Rosyth. Shortly afterwards he began manufacturing Riefler escapement clocks in airtight cases. Of these he made two himself, the first going to Greenwich and the other to the Royal Alfred Observatory at Mauritius. It was after this, when another clock was required for Hong Kong Observatory, that he went into partnership with Messrs. T. Mercer & Sons of St. Albans. Three clocks were manufactured, one going to Hong Kong, one being kept by Mr. Mercer, and one by himself. The one which he kept is being offered to the Science Museum at South Kensington.

Cottingham was one of the four observers who took part in the eclipse expeditions of 1919 May 29, at which the Einstein deflection of light was first confirmed. He and the writer went to the Isle of Principe in the Gulf of Guinea. This expedition, although less fortunate in the weather than the other expedition, had some success; and two photographs, obtained through thin cloud, gave the deflection value $1''.61 \pm 0''.30$.

To Cambridge Observatory he was a good friend and benefactor. For more than thirty years he was, in fact if not in name, an honorary keeper of the clocks, visiting them regularly and freely undertaking their cleaning, repair and adaptation to varying needs.

He took especial delight in the older clocks by famous makers, which appealed to his intense love of good workmanship. The Society is indebted to him for the account of its Harrison clock published in *M.N.*, 70, 25.

Although clocks and time-keeping were his main interest, he sometimes undertook other work of a technical scientific kind. In 1904 he installed the pumping machinery at a sewage works. Later he installed electric-light plant at a number of country houses in Northamptonshire and elsewhere. He also installed pyrometers in blast furnaces at Corby, Wellingborough, Kettering and Walsall. He had a keen interest in all applications of science. As his companion on a distant eclipse expedition, I have vivid recollection of his insatiable curiosity as to all that he saw. Apart from matters connected with his work, his one great interest was Freemasonry; he was a Past Master of Chicheley Lodge, No. 607, and also Past Provincial Grand Treasurer of Northants and Hunts.

He died on 1940 March 20, leaving a widow and one son, L. G. Cottingham, F.B.O.A., F.S.M.C. For most of the foregoing particulars I am indebted to his son "who has many memories of being made to do a thing over again because it did not conform to his father's standard."

He was elected a Fellow of the Society on 1905 May 12.

A. S. EDDINGTON

GEORGE STUART FORBES, who died at Sevenoaks on 1940 April 17, had been a Fellow since his election on 1898 May 13. He had a most distinguished career in the Indian Civil Service and was one of its senior former members.

He was born on 1849 October 27 at Forgue and was educated at Aberdeen Grammar School and later at Aberdeen University, from where he took the examination for the I.C.S. seventy years ago. He went to India in 1872 where he was posted to Madras, with which Province he was mainly associated throughout his life. He held many important posts during his period of service, chief among them being those of First Secretary to the Resident in Hyderabad, Secretary for Berar, Secretary and later Chief Secretary to the Government of Madras. Many legislative reforms in the Province were due to his initiation and skilful pilotage through their legal course. He completed his distinguished career in India as a member of the Madras Executive Council from 1906 to 1909.

Forbes was made C.S.I. in 1904 and promoted to the knighthood of the Order five years later.

It is not surprising that with such a busy life in India, Forbes's interest in astronomy should have been general and not specialised. Throughout the later part of his life he kept in touch with the developments of astronomical science, and followed the rapid advance of astrophysics with particular interest, though the highly specialised technical details made more than a general grasp of progress difficult to assimilate.

ALFRED FOWLER. Alfred Fowler, who died last June at the age of seventy-two, had a remarkably interesting career. Owing nothing to fortune and as little to influence or self-seeking, he had attained to a position of recognised scientific eminence. A few years later his upward path might have been easier, a few years earlier lack of opportunity would almost certainly have made it altogether impossible. A Yorkshireman by birth, he inherited a sturdy character which carried him unruffled through the difficulties and disappointments of life and served him well.

Born in 1868, Fowler received his early education in the local schools of his native county. In his fifteenth year he proceeded with an exhibition to South Kensington, and this was to be the beginning of his association with the Royal College of Science (at that time the Normal School of Science) which was to last all through his active life. Beginning as a student by gaining distinction in Mechanics, he passed the next five years.

in various capacities before he received in 1888, at the age of twenty, a definite appointment as demonstrator in astronomical physics. Thus his scientific life started early, for even at that time his work under Norman Lockyer had already begun some years before.

The temperaments of the two men, Lockyer and Fowler, presented so strong a contrast that serious differences might be expected to arise. The suspicion, if formed, is without real substance. Lockyer was the masterful chief, Fowler was the patient and loyal assistant. He could afford to bide his time. Even in 1901, when Lockyer retired, Fowler was barely thirty-three. In reality the qualities of the two men were complementary and the combination was fruitful. Lockyer was intuitive and boldly imaginative. Fowler's genius was of the kind which consists in taking infinite pains. Each in his own way was inspired by a genuine enthusiasm and the subject of astrophysics was at a stage when the sacred flame burned brightly.

One thing is quite certain. Fowler was first and foremost an astronomer at heart. For him physics was a tool to be used in the service of astronomy; he was not a physicist who found a laboratory in the stars. Thus his interest in eclipses was always great and he took a prominent part in six expeditions. Those of 1896 and 1905 were frustrated by cloud, and in 1914 war broke out before the destination in Russia could be reached. But the expeditions to West Africa (1893) and to India (1898) led to notable results in the first record of the flash spectrum and the first accurate measurement of the green coronal line. A journey to Spain in 1900 was less successful. In this direction the influence of Lockyer can be seen and it persisted to the end of Fowler's life.

During the years of association with Lockyer a large part of the spade-work fell to Fowler and became merged in the general activities of the observatory when the stage of publication was reached. This applies to the important researches on the classification and interpretation of the enhanced lines. To the experience of those years may be traced a characteristic note in Fowler's scientific philosophy. He had seen theories come and theories go, and he was not disposed to rate them over highly; whereas, he would say, measurements if accurate are unassailable and their value is permanent.

In 1901 Lockyer retired and Fowler was appointed Assistant Professor of Physics with the charge of the astronomical department. Unfortunately he was left with no astronomical equipment; the decision to remove the instruments assembled in the time of Lockyer was one to which he was never reconciled. This step might have induced in another man a sense of frustration, but not in Fowler. If one line was closed, there was always something else to be done. He had acquired a mastery of the technique of spectroscopic research and had gained a mass of experience. He would continue with the laboratory work, with such means as he had at his disposal. This is what he did, and it brought him fame.

His first researches in an independent position had a direct astronomical bearing. An investigation of the titanium oxide bands accounted for the characteristic features in the spectra of M-type stars, and a study of the spectrum of magnesium hydride identified features occurring in sunspot spectra. These are the main results of work which firmly established Fowler's reputation among astronomers. At the same time he was continuing to study atomic spectra and their series relations, for which he had a peculiar aptitude. This work culminated in the Physical Society Report (1922) on Series in Line Spectra.

So far Fowler had been working as it were in the dark, with no light from atomic theory. It is generally allowed that he displayed an uncanny power of vision in the task. In reality, apart from a natural gift, he was guided by an unequalled familiarity with the medium in which he moved, an intimacy dating almost from his boyhood. But the limitations of contemporary ideas were illustrated by Pickering's ζ Puppis series, which Rydberg attributed to hydrogen. What was supposed to be the first line of the principal series was found in the star and also by Fowler in the chromospheric spectrum at the

1898 eclipse. A helium tube with a trace of hydrogen gave him the same line, but when this was accidentally broken the conditions were never reproduced until 1912. Then success attended his efforts, and not only the expected but a second allied series were obtained. There were two reasons to suspect the attribution to hydrogen, for in the first place the helium content of the tubes was greatly in excess of the hydrogen and in the second the measured wave-lengths differed sensibly from the predicted. Nevertheless prevailing ideas were too strong, and Fowler, though clearly not satisfied in his own mind, accepted the common interpretation. The matter was in this state when Bohr's theory of the Balmer series positively demanded a corresponding series for ionised helium. Fowler's work immediately filled the bill and all that was necessary was a change of label.

As in this case, when atomic theory advanced to greater refinement Fowler was in a position to supply the numerical data needed. Thus the first accurate determinations of the Rydberg constant and the mass ratio of electron and proton were by-products of his work. There is a remarkable unity in the greater part of all this work, for it began with the study and classification of enhanced lines under Norman Lockyer, and it culminated in the investigation of atomic radiation in different stages of ionisation. Experimental evidence that these are aspects of one process may be regarded as the subject of Fowler's first Bakerian Lecture in 1914, while his second Bakerian Lecture ten years later affords a most beautiful illustration of the process when the silicon atom loses its electrons in successive stages. The results are stated in terms of ionisation potentials and modern physical theory has changed the point of view. But the germ is still to be seen in Lockyer's groups *Si* I, II, III and IV of lines distinguished in the laboratory and in the stars.

In the meantime Fowler had become Professor of Astrophysics in 1920, having enjoyed the title without the emoluments for some years before that. Only a short time elapsed before, at the end of 1923, he was appointed one of the first Yarrow Professors of the Royal Society. His connexion with what had now become the Imperial College continued till his retirement in 1934, but he was now relieved of all ordinary teaching duties. The clarity of exposition which he had at his command must have made him an admirable teacher, and to the research students who came to him from all quarters his example was infectious and inspiring. Unfortunately the six years of his retirement were marred by failing health.

If in the end physics claimed Fowler's services as a spectroscopist at the expense of astronomy, this was the result of circumstances rather than of inclination. When the International Astronomical Union came into active existence in 1920 Fowler was persuaded to undertake the duties of General Secretary. It was a task for which he was well qualified by experience of the Solar Union during the ten years before the war of 1914. He took a leading part in organising the new body and nursing it through its early critical years. Apart from the work of general administration, which lasted for three years or more, he played a large part on the commission which deals with Standards of Wave-length.

A curious interest attaches to Fowler's first election to the Council of our Society, and there can be no harm now in recalling the incident. At the end of the last century Council had tended to become something like a close corporation and had lost contact with a considerable body of the Fellows. Members of Council were commonly re-elected year after year, and when a new choice became necessary (as a rule by death) the additional candidate was usually found in a narrow clique. It is true that a remedy was provided then, as it still is, by the clause which allows any Fellow to substitute another name for any one printed in the Council's list. But in practice the clause is apt to be ineffective, because it needs a sufficient number of Fellows to unite not merely in support of one candidate but against one particular official nominee. At last, in 1904, the necessary combination was successfully organised, and an unofficial candidate was duly elected.

The proceeding is clearly open to grave objection, and in recent years a practice has been adopted which ensures an influx of fresh blood. But the action taken in 1904 was salutary and Council gained a most valuable recruit. For it was Alfred Fowler, who retained his seat without question till 1912, when he was elected Secretary. After filling this office for six years he was elected President (1919-21) and later served the Society for five years as Foreign Secretary (1931-36). On the constitutional point it is interesting to observe that he became ineligible for re-election to Council by the modern practice and had only recently returned after a short interval at the time of his death.

By his services to science not only in the form of research and teaching, but by conscientious attention to the affairs of various institutions and committees of national importance too numerous to mention individually, Fowler had more than earned the C.B.E. which came to him in 1935. He received honorary doctorates in science from four English universities, Cambridge, Durham, Bristol and Leeds. He was a corresponding member of the Paris Academy of Sciences in the section of Astronomy and foreign associate of the National Academy of Sciences at Washington. Among the special distinctions which came his way were the Gold Medal of the R.A.S. (1915), a Royal Medal of the Royal Society, the Bruce Medal of the A.S.P., the Henry Draper Gold Medal for Astrophysics and the Valz Prize of the Paris Academy of Science. The whole forms an impressive list, and it is pleasant to reflect that a man of so unpretentious and modest a disposition did not fail of his due meed of recognition and reward. It was this simple character coupled with ungrudging devotion to all scientific causes which enlisted his sympathy that endeared him to many friends no less in America than in this country.

Alfred Fowler is survived by his widow and a son and daughter. He was elected a Fellow of the Society on 1889 December 13.

H. C. PLUMMER

UMESH CHANDRA GHOSH died in March 1939 at the age of seventy-four. His home was in the district of Hugli in Bengal, but as his father was a teacher in Calcutta, Ghosh was brought up and received his early education there. He proceeded in due course to the University of Calcutta where he had a very successful career, leaving, in 1890, with a high mathematical degree. After short appointments as professor of mathematics in the City College, Calcutta, and in the Krishnagar and Agra Colleges, he finally settled down at Allahabad as professor in the Muir Central College, which position he held, with great credit to himself and advantage to his pupils, for twenty-seven years.

He had a keen interest in astronomy and was a Fellow of the Society for nearly forty years. In later years he became deeply held by Hindu philosophy and literature, and in the ancient Hindu religion. His astronomical knowledge was put to considerable use in calculating the dates and times of historical religious events from the internal astronomical evidence.

He was loved and respected by all persons with whom he came into contact for his amiable and kindly disposition, and for his hospitality, which was extended to friends and strangers alike; he lived a quiet, studious and religious life, and his death will be mourned by his many friends and pupils.

LAWRENCE NEVILLE HOLDEN, who died suddenly at his home in Lancaster on 1940 March 14, only just missed celebrating the golden jubilee of his election as a Fellow, which took place on 1890 November 14.

Born in Lancaster on 1864 February 8, Holden was the son of the late Lawrence Holden, solicitor and coroner of the Lancaster district for fifty-two years until 1906; he was destined to follow in his father's footsteps and so to form a family association with the coronership that lasted more than eighty years. He received his early education

at Lancaster Royal Grammar School and was admitted as a solicitor in February 1889. Thereafter he took over his father's appointments one by one, being appointed deputy coroner to his father in 1891, succeeding to the post of Coroner in 1906, and following his father as Registrar of the County Court in 1908. The family association with the law was continued in other less official capacities, Holden succeeding his father as honorary secretary of the Lancaster Law Society in 1910; they together held the post continuously from 1856.

As can well be imagined, with such a record of public service, Holden was a leading figure in local circles and moreover continued to serve the community in all those matters for which his upbringing and training so peculiarly fitted him: for over eighteen years, for instance, he served as secretary of the Royal Lancaster Infirmary.

Holden was elected a Fellow of the Society in 1890 when he was early interested in astronomy and meteorology. Long service in many capacities was the keynote of his devotion, no less to his work and social activities than to his scientific interests; for over a quarter of a century he was honorary director of the Greg Observatory, principally devoted to the recording and compilation of meteorological records. His interests were rather meteorological than astronomical, though he contributed many popular articles on the Aurora Borealis and similar phenomena to local newspapers. He was a founder member of the Lancaster Astronomical and Scientific Society.

Holden is survived by a widow and a married daughter.

JAMES GALL INGLIS was elected to Fellowship of the Society less than three months before his death on 1939 April 6; but he had a long record of service to Astronomical Science in his native city of Edinburgh, being one of the first members, and for some time President, of the Edinburgh Astronomical Society. He was born in 1865, the son of Robert Inglis, head of the firm of Gall & Inglis, publishers of Ready Reckoners for various purposes, of road books of England, Scotland and Ireland, etc., and of some astronomical works, notably Norton's Star Atlas. In 1939 he published under his own name a very much revised and improved edition of *An Easy Guide to the Constellations: with a Star Atlas*, originally written by his grandfather, the Rev. James Gall. His inclination on leaving school was to take a degree in Science in the University, but on the death of his father it became necessary to devote himself to the business of the firm, of which he was manager for a long period of years: many of its publications were written or edited by him.

He was a Fellow of the Royal Society of Edinburgh, a Vice-President of the Scottish Mountaineering Club, and was prominent in religious work, having taught for fifty years in the Sunday School of the congregation to which he was attached. He is survived by his wife and by one son, who succeeded him in the direction of the firm of Gall & Inglis.

AUGUSTUS EDWARD HOUGH LOVE, born 1863 April 17 at Weston-super-Mare, was the son of a surgeon, and was educated at Wolverhampton Grammar School. He went into residence at St. John's College, Cambridge, in 1882 as a Sizar, and was elected Scholar in 1884. His mathematical career was a brilliant one; Second Wrangler in 1885, he was classed in the First Division of Part III of the Tripos in 1886, and in that same year was elected a Fellow of his College. He was First Smith's Prizeman in 1887. Whilst College lecturer, and later as one of the small number of University lecturers, he published a number of papers covering a wide range of topics in hydrodynamics and elasticity. He was elected a Fellow of the Royal Society in 1894, and became a Fellow of the R.A.S. in 1907.

In 1898 Love was elected to the Sedleian Chair of Natural Philosophy at Oxford, a Chair which he occupied until his death on 1940 June 5. All his work was character-

ised by great care and thoroughness, of which his monumental *Treatise on the Mathematical Theory of Elasticity* is perhaps the best example. His lectures were carefully prepared, and one of his former pupils tells of the way in which he would illustrate his lectures on dynamics by the use of a large gyroscope, which he brought with him in a taxicab (in later years at any rate). Throughout his residence in Oxford he was a member of the Common Room of The Queen's College, of which college he became a Professorial Fellow in 1927.

In the early years of this century he made a number of important contributions to the theory of the propagation and scattering of electric waves. Of his papers that have a direct or indirect astronomical interest the following may be mentioned:—

On Dedekind's theorem concerning the motion of a liquid ellipsoid under its own attraction (1889).

On the oscillations of a rotating liquid spheroid and the genesis of the Moon (1889).

On Sir William Thomson's estimate of the rigidity of the Earth (1894).

The gravitational stability of the Earth (1908).

Note on the representation of the Earth's surface by means of spherical harmonics of the first three degrees (1908).

The yielding of the Earth to disturbing forces (1909).

The last three are linked with the subject-matter of the Essay *Some Problems of Geodynamics* that won for Love the Adams Prize in 1911. As it happens, the best-known result in that Essay is one that stands a little aloof from the general programme. There was an outstanding difficulty in fully accepting Oldham's interpretation of the "Long-wave phase" in earthquake records as the arrival of waves travelling over the surface of the Earth. The only type of surface wave that theory had hitherto predicted was the Rayleigh wave, in which there is no displacement in a direction lying in the surface and transverse to the direction of propagation; yet a typical seismograph record has strongly marked transverse displacements in the long-wave phase. It was Love's discovery of the possibility of the existence of transverse waves in a heterogeneous medium (Chapter XI of the Essay) that resolved the seeming discrepancy; for these waves the term Love Waves was introduced by Jeffreys, and although printers' readers have been known to query it from time to time this name is well-established in seismological literature. It was in the 1909 paper just cited that Love introduced the numbers h and k , expressive of the yielding of the Earth to tidal forces and the corresponding disturbance of the gravitational potential; these are sometimes referred to as "Love's numbers."

In addition to the two books already mentioned, Love was well known for his text-book *Theoretical Mechanics*. Those who were privileged to receive their first introduction to differential and integral calculus through Love's elementary text-book will readily acknowledge their gratitude.

Love received from the Royal Society a Royal Medal in 1909 and the Sylvester Medal in 1937. In 1926 he was De Morgan Medallist of the London Mathematical Society, of which he was Secretary 1890-1910 and President 1912-13. In 1927 he was elected an Honorary Fellow of St. John's College, Cambridge.

R. STONELEY

EDMUND NEVILLE NEVILL was born at Beverley, Yorkshire, on 1849 August 27, and was educated at Harrow and New College, Oxford. He acquired an early interest in science, particularly in astronomy and chemistry, and was elected a Fellow of the Society in 1873 under the name of Edmund Neison, having the curious idea that it was derogatory to the holder of an ancient name to make a career in science.

In his early years his astronomical work was mainly in selenography. His observations of the Moon were made at his private observatory at Hampstead with a 6-inch

equatorial of fine definition and later with a $9\frac{1}{2}$ -inch With-Browning reflector. In 1876 he published a large volume, *The Moon and the Condition and Configuration of its Surface*, in which he incorporated the results of observations by Mädler, the Rev. T. W. Webb and others, as well as by himself. He had revised the great lunar map of Beer and Mädler, with the aid of his own sketches and sketches supplied to him by other amateur observers, and he had made numerous measures of position of the various lunar formations, as well as of their dimensions and brightness. This volume did much to stimulate an interest in selenography and still remains a recognised authority.

Nevill was also interested in the theory of the motion of the Moon. In his first paper on this subject, communicated to the Society in March 1877, he confirmed the reality of an inequality in the longitude of the Moon, produced by the action of Jupiter, which had been discovered by Professor Newcomb in the previous year; he determined the coefficient of this inequality and obtained a value very near the truth. The theory of the Moon's motion was at this time in an interesting stage. There was an increasing discordance between observation and the positions of the Moon computed from Hansen's Tables, which had been published by the British Admiralty in 1857. Newcomb in 1878 concluded that either the theory was inadequate or the rotation of the Earth was subject to fluctuations of irregular character. The immediate need was the perfection of the theory of the Moon's motion, in order to decide whether important terms had been omitted from Hansen's Tables or whether the coefficients were in need of revision. In 1877 Nevill published in the *Memoirs R.A.S.* a lengthy paper containing the theoretical foundation on which to base a complete analytical development of the lunar theory, devised to simplify the older methods of treatment. In 1884 he published another long memoir on the corrections required by Hansen's Tables.

Meanwhile Nevill had gone to South Africa as Government Astronomer for Natal. There had been under consideration for several years a proposal for the establishment of an observatory in Durban. The observatory was started in 1882, with the aid of sums voted by the Corporation of Durban and by the Legislative Council of Natal, a Grubb 8-inch equatorial being presented by Mr. Harry Escombe. Mr. (later Sir David) Gill, H.M. Astronomer at the Cape, had been consulted and Nevill received an urgent telegram from Gill, offering him the post of Government Astronomer. He sailed almost on twenty-four hours' notice on 1882 October 27, reached Durban on November 27 and, in accordance with instructions furnished by the Colonial Secretary, he took possession of the Observatory on December 1 as Astronomer to the Natal Government. On December 6 he obtained successful observations of the transit of Venus, for which the conditions were exceedingly fine.

Nevill had planned a programme of work comprising various observations to obtain data for perfecting the Tables of the Moon. The observations were to include a determination of the parallactic inequality; a study of the systematic effects of irregularities of the limb on the apparent place of the Moon; the effect of irradiation on the apparent diameter; and the determination of the real libration of the Moon. Meanwhile he continued assiduously his investigations in lunar theory. Memoirs were planned dealing with the mathematical investigation of the theory of the terms of long period in the expression for the Moon's longitude produced by the disturbing action of the planets, and with the calculation from theory of every term of long period exceeding in maximum value one-tenth of a second of arc.

But lack of financial support soon made itself felt and work had more and more to be restricted to routine observations—determinations of time for the provision of a time-service, meteorological and tidal observations. In 1888 Nevill was appointed Government Chemist and Official Assayer for Natal, and combined this office with that of Government Astronomer until his retirement. He had always been interested in chemistry, and in earlier years he had been amongst the younger Fellows of the Chemical Society who agitated for the establishment of an Institute to represent the profession of

chemistry. The outcome was the formation of the Institute of Chemistry, of which Nevill (under the name of Neison) was one of the original Fellows, and a member of its Council from 1877 to 1880. He acted as Honorary Corresponding Secretary of the Institute for the Natal Province.

The Natal Observatory came to an end in 1911 and Nevill, who had been elected a Fellow of the Royal Society in 1908, returned to England to live in retirement at Eastbourne. The bulk of the researches of the years before his retirement and his lunar tables remain unpublished. The problems on which he had been engaged had been solved by E. W. Brown in his theory and Tables of the Moon. Nevill had hoped, by improving and extending Hansen's theory and Tables, to bring about agreement between observation and prediction. We now know that this is not possible because of the non-uniformity of the Earth's rotation. Thus Nevill was engaged upon what was essentially a vain quest. Nevertheless, his work was of value and was one of the stepping-stones to the final elucidation of a problem that had engaged the attention of some of the greatest mathematicians and geometers for more than two centuries.

Nevill reverted to his family name in 1888, in accordance with the conditions of a will. He married in 1894 Mabel Grant, who, with three children of the marriage, survives him. He was a keen lawn-tennis player and was much interested in Babylonian history, which occupied him after his retirement. He died on 1940 January 14 in his ninety-first year.

H. SPENCER JONES

EDGAR GIRARD CROKER POOLE was born on 1891 June 6, the son of Major W. Croker Poole, R.A.M.C. He was educated at St. George's School (Ascot) and Rugby, going up from there to Queen's College, Oxford, in 1910 with an open scholarship in mathematics. He had a distinguished undergraduate career at Oxford, but this was interrupted by the Four Years' War. Here he served with distinction in Intelligence, first at the Admiralty and then at G.H.Q., France. After the war he returned to Oxford and mathematical research. In 1929 he was elected Fellow and Mathematical Tutor of New College, a post that he held till his death in July 1940.

He was elected Fellow of the Society in 1929. He had previously been a member of the London Mathematical Society and served on its Council from 1927 to 1931, and had in this way enjoyed the privilege of meetings in our rooms in Burlington House. This was, perhaps, his first link with the Society, for he was not primarily an astronomer, though his earliest investigation was of geophysical interest. Its subject was a point in the theory of tides suggested to him by Professor A. E. H. Love with whom he was then working. For the rest, his researches were in the borderland between pure and applied mathematics: he was much interested, for example, in hydrostatics and in the application of conformal representation to physical problems. In his later years he worked more particularly at the theory of differential equations and functions defined by differential equations. His book, published in 1936 by the Clarendon Press, he described as an "Introduction to the theory of linear differential equations." His other researches appeared in some twenty papers, mostly in the *Proceedings* and *Journal of the London Mathematical Society* or in the *Quarterly Journal of Mathematics*. When this latter periodical was taken over by the Clarendon Press (in 1929) on the death of Dr. J. W. L. Glaisher, Poole became one of three editors, bringing to the task an encyclopædic knowledge and high critical standards.

He had a gift for languages and was widely read both in the classics of mathematical literature and in more recent works: in his rooms at New College he had brought together a distinguished collection of mathematical books. In whatever he undertook he was conscientious to a fault and, as many of his friends felt, too diffident of his own powers. In this way an over-appreciation of the difficulties of the problem on which he was engaged and his scrupulous respect for the work of others combined to restrict

his output of original work and to disappoint expectations justly founded on his great talents.

In his writing as in his teaching Poole was profound rather than brilliant, hating the slipshod and specious argument. This gave something of a classical austerity to his work, but sometimes deterred the less persevering undergraduate. He was happy, however, in attracting and teaching a number of very able pupils. These he encouraged to read wisely and deeply, eschewing clever devices but seeking knowledge of mathematics as a whole, and they have gone out into the mathematical world maintaining these traditions in mathematical teaching and research.

In his personal relations he was rather shy and reserved, but a good friend and colleague. As a bachelor he entertained with charm and distinction. He went abroad a good deal, to Paris or to the Alps. Mountains, with swimming and folk-dancing, were his chief recreations. He was a Freemason and had been Master of the Apollo University Lodge.

T. W. CHAUNDY

SIDNEY HERBERT POPE, who was born at Folkestone in 1886, was one of the many newspapermen who have been and are Fellows, and who are in a peculiarly happy position to be able to share their sincere interest in astronomy with the general public through the columns of the daily newspapers. To give the public a true picture of astronomical events and phenomena in simple language is performing a great service to the science of astronomy as well as to the public, the majority of whom have at heart a latent interest in all matters astronomical, requiring only encouragement to bring it to the surface.

For many years prior to his death, Pope was on the staff of Allied Newspapers Ltd., for which he wrote extensively on astronomical subjects, revealing his ability and talent for making astronomy of real and vital interest to "the man in the street." The eclipse of 1927 gave him an opportunity for using his abilities to the full and he wrote numerous brilliant articles for the London and Manchester papers. An indication of the respect with which his articles were received by professional astronomers is shown by the refusal of Sir Frank Dyson, then Astronomer Royal, to contribute a series of articles on the eclipse for Allied Newspapers, on the grounds that they had on their staff a man who could, in his (Sir Frank's) opinion, write the articles equally well. It was this eclipse that led to his election as a Fellow, on the nomination of the late Major Hepburn, on 1928 February 10.

He possessed two telescopes, a 3-inch refractor and a 10-inch reflector, which he used as frequently as his work would permit. After his death on 1940 May 12 his son presented these instruments and the whole of his astronomical library to the British Astronomical Association.

HENRY JOHN SPOONER was born on 1856 June 16 and died on 1940 December 16. He had a distinguished career in the field of engineering. His first appointment in 1879 was as lecturer on engineering at the Royal Small Arms Factory, Enfield, and the Waltham Powder Mills. In 1882 he was appointed principal lecturer on mechanical science at the School of Engineering at the Regent Street Polytechnic, and four years later became a director and professor of mechanical and civil engineering. This position he retained until his retirement in 1922. During this time he also practised as a consulting engineer.

During the last war Professor Spooner was honorary technical adviser to the King George Hospital and to the Union of South Africa in connection with vocational work at the military hospital in Richmond Park, besides supervising intensive training courses for war workers.

He was interested in and lectured on the application of science to social problems.

Distinguished abroad as at home, Professor Spooner was a recipient of the orders, Knight Commander of the Royal Order of St. Sava, Serbia (1895), and Knight of the Golden Cross of the Redeemer, Greece (1907).

He was elected a Fellow of the Society on 1935 April 12.

EVAN GWYN WILLIAMS was born on 1905 October 13, the elder son of the late Christopher Williams, artist and portrait painter. He died in Pretoria on 1940 May 31 after an operation.

He was educated at the Froebel Educational Institute School, the King Alfred School, Hampstead, and Trinity College, Cambridge, where he graduated in Natural Science in 1926. He then spent a year in London studying under Professor A. Fowler and Mr. C. C. L. Gregory, followed by three months at the Norman Lockyer Observatory. In the autumn of 1927 he returned to Cambridge to do research work at the Solar Physics Observatory. Two years later he was awarded an Isaac Newton Studentship and in 1931 a Commonwealth Fund Fellowship, with which he went to Mount Wilson for two years. He then returned once more to Cambridge and in 1936 was appointed to the staff of the Solar Physics Observatory. A year later he took up the post of Second Assistant at the Radcliffe Observatory, Pretoria.

Williams published eight major papers, two of these being in collaboration with other men, and a number of shorter articles—an impressive record for a comparatively short career. His first paper, on the effect of temperature and surface gravity on hydrogen line contours, appeared in the *Annals of the Solar Physics Observatory*. Then followed four papers in the *Astrophysical Journal*, the result of work done during his two years at Mount Wilson. These deal with the spectrophotometry of B-type stars and include a discussion of the relation between colour excess and interstellar calcium line intensity and a scheme of classification for these stars. His later work at Cambridge resulted in two papers on the contours of bands in Nova Herculis, and with D. L. Edwards he wrote a second paper on the classification of B-type stars, all of which appeared in the *Monthly Notices*.

In Pretoria he was engaged at the time of his death on an observational programme on the magnitudes of southern B-type stars in three colours, using the 7-inch finder of the yet unfinished reflector. He also observed the Cepheid variables, ι Carinae and β Doradus, in a similar manner. The results of as much of this work as he had completed will be communicated to the Society in due course.

He was a member of two eclipse expeditions, that of Professor Stratton to Canada in 1932 and that of Professor Carroll to Omsk in Siberia in 1936. The first of these was entirely unsuccessful owing to cloud, but at the second Williams observed some new lines in the Paschen series of hydrogen. He was to have used Professor Carroll's interferometer at Calvinia on 1940 October 1.

Gwyn Williams had a pronounced artistic sense and considerable skill with his fingers, both of which gifts proved of great value in the early days at Pretoria, when the telescope turret, office and residences were rising from the rough hill-top and mounds of building refuse had to be converted into gardens. But perhaps his chief characteristic was his love of observing. While still a boy he had become intensely interested in nature in its various manifestations, and he filled countless notebooks with descriptions of all that he saw. So it was natural that later he should become an astronomer in the truest sense—he had to observe all that was observable. And yet he did it in his own way. He was never content to follow other people's methods. It is perhaps due to this that he had such an engaging personality. Indeed he proved himself a delightful colleague and a loyal friend. It is sad that he did not live to see the completion of the 74-inch reflector, and with it to explore the mysteries of the southern skies, a task to which he was so keenly looking forward. For he had the urge to explore,

and expressed it in his love for mountains, spending many of his holidays among those of Wales and Scotland.

He married Fiona Lauder in 1937, and his wife and a young daughter survive him. He was elected a Fellow of the Society on 1928 March 9.

H. KNOX-SHAW

PROCEEDINGS OF OBSERVATORIES

Council has decided to omit the reports of the proceedings of observatories during the year 1940. The war has led to disorganisation in a smaller or greater degree for all the observatories for which reports are normally published, and in many cases the reports would merely have to record the suspension of observing programmes rather than their inception or continuation. Reports covering 1940 will be incorporated with those for a future year.

REPORTS ON THE PROGRESS OF ASTRONOMY

THE ESCAPE OF CONTINUOUS RADIATION FROM STELLAR ATMOSPHERES

1. The present note is confined to a survey of the study of problems connected with the emission of continuous radiation from stellar atmospheres—that is, the emission of radiation at wave-lengths not affected by proximity to spectral lines. From a strict theoretical point of view it must be recognized that the escape of radiation from the atmosphere of a star cannot be separated into two wholly independent processes, and that the distribution of continuous radiation throughout the spectrum must be affected to some extent by the presence of spectral lines. Nevertheless it is believed that a fair approximation can be obtained if, in the first place, we ignore the presence of the lines and assume that the escape of continuous radiation is dominated by true absorption, whereas in the study of line profiles scattering plays an important part.

Up to quite recently research, both observational and theoretical, on the problem has been influenced by the belief that the distribution of radiation throughout the continuous spectrum of a star was, to a good degree of approximation, that emitted by a “black-body” surface at a temperature corresponding to the “effective temperature” of the star. As will be pointed out below, this assumption is equivalent to the assumption that the absorption coefficient of the stellar material is approximately independent of frequency, and there seemed indeed to be good reasons, both observational and theoretical, for believing the assumption to be justified. On the observational side spectrophotometric determinations of the distribution of continuous radiation did seem to show that the curves obtained were black-body curves within the error of observation, and on the theoretical side the assumption that the absorption coefficient was independent of wave-length led to theoretical values for the centre-limb contrast of the Sun which were in good agreement with the observed. It was consequently taken for granted that the stars radiated approximately as black bodies, and that the conditions in stellar atmospheres were sufficiently close to equilibrium conditions to justify the application of the Fowler-Milne ionization formulæ (*M.N.*, 83, 403, and 84, 499) which, provided the partial electron pressure in a stellar atmosphere was known, gave the “temperature” at which various spectral lines attained maximum strength—that is, the “temperatures” corresponding to various spectral types. From the available spectrophotometric determinations of temperature and from other considerations a partial electron pressure of about 10^{-4} atmospheres was adopted, and ionization temperatures deduced. The “temperatures” in the Fowler-Milne formulæ were taken to lie between the average temperature of the reversing layer and the effective temperature of the high-frequency radiation responsible for ionization by photo-electric effect. For “black-body” stars the latter would be roughly equal to the effective temperature of the star, and the former would be between this and the boundary temperature, which, for such stars, is about 20 per cent. less than the effective. It seems safe to assume that the ionization temperatures given by the Fowler-Milne formulæ are within 10 per cent. of the effective temperatures of “black-body” stars.

The “temperatures” given by the Fowler-Milne formulæ for stars of types O9–B0, B1 and B2 were 26,500°, 19,000° and 16,500° respectively, whereas the temperature for spectral type A0 was 10,000°. If the stars were really black bodies these values would be obtained by direct spectrophotometric observation, and an attempt was made at Greenwich in 1925 and 1926 to verify this. Relative spectrophotometric “gradients” were measured between stars of types A and B, and using 10,000° as the A0 temperature,

the average result for the B₁ and B₂ stars (excluding the "yellow" B₁ star ζ Persei) was only 13,400°. The difference between 13,400° and 10,000° corresponds to a gradient difference (see section 3 below) of 0.30, whereas the gradient difference between B₂ and A₀ predicted by the Fowler-Milne theory is 0.47, corresponding to the temperature difference 16,500°–10,000°. Subsequent observations have fully confirmed the conclusion that the relative gradients between the early-type B stars and the A₀ stars are less than those which should be obtained if the Fowler-Milne values were identical with the spectrophotometric temperatures. In the final Greenwich list of relative gradients (*M.N.*, 100, 189) of 250 stars, in which zero gradient corresponds to mean A₀, the largest negative gradients are those for γ Pegasi (B₂) and β Cephei (B₁), the values for each of these stars being –0.30, whereas using the Fowler-Milne values, the calculated gradients for B₂ and B₁ are –0.47 and –0.56. Since the measurement of relative gradient permits of high accuracy, the probable errors being ± 0.02 or less, it is evident that the ionization temperatures given by Fowler and Milne cannot be identified as they stand with spectrophotometric colour temperatures. It follows that either the black-body approximation is seriously in error, or that the value for the partial electron pressure adopted by Fowler and Milne will have to be radically changed. It was in fact noted in 1926 (*M.N.*, 87, 362) that if a partial electron pressure of 1.1×10^{-2} atmospheres is used, the Fowler-Milne formulæ then give 13,000° for A₀ and 20,300° for B₂, corresponding to a gradient difference of 0.31. Absolute spectrophotometric measurements have since given a value of 15,600° for the A₀ stars, but the accuracy of absolute measurements in gradient units is less than those of measures of relative gradient, and it would be just possible to maintain that a value in the neighbourhood of 13,000° for the colour temperature of A₀ stars is consistent with the observational evidence (see section 3 below). So, by adopting a high value for the pressure (which would, however, probably lead to difficulties in other connections), it would be just possible, as far as the evidence provided by colour temperature work in the visible spectral range goes, to regard the black-body approximation as a good one and to identify the Fowler-Milne ionization temperatures with the effective and colour temperatures (for definitions of these quantities see section 2 below).

2. *The Balmer Discontinuity.*—But by 1926 evidence of quite another kind was available, which shows that the stars cannot be regarded as even approximately black-body radiators. As early as 1876 Huggins had drawn attention to a discontinuity in the continuous spectra of α Lyræ and other class A stars at about the wave-length of the series limit of the Balmer lines. The discontinuity was first studied quantitatively by Ch'ing Sung Yü (*L.O.B.*, 375), and in recent years the accurate measurement of the discontinuity has been the subject of valuable spectrophotometric researches by Arnulf, Barbier, Chalonge and other French astronomers (*Annales d'Astrophysique*, 1, 293, 402; 2, 479). From these results it appears that, like the Balmer lines themselves, the discontinuity, which consists normally of a sudden diminution in the intensity of the continuous spectrum as we pass to the short wave-length side of the Balmer series limit, is at a maximum at about type A₀, the discontinuity being about 1.2 magnitudes for normal A₀ stars (for supergiant A₀'s it is less, and the maximum discontinuity seems to occur near type F₀ for supergiants). This means that the intensity of the continuous spectrum of an A₀ star at a wave-length a little higher than that of the Balmer series limit is about three times the corresponding intensity at a wave-length just below the limit.

It seems clear that for such a star the continuous spectrum cannot even be approximately regarded as that of a black body. Defining, as usual, the *effective temperature* of a star as that temperature at which a black body will radiate the same amount of energy per unit area of surface as the star actually does radiate, it follows that if we construct a diagram in which the energy emitted by the star per angstrom per unit area of surface is plotted as ordinate against the wave-length as abscissa, then since the

total area enclosed between this curve and the wave-length axis must be the same as the corresponding area for a black-body curve at the star's effective temperature, the existence of the discontinuity will involve that the actual curve for the star is sometimes above and sometimes below the black-body curve. This means that what is called the brightness temperature of the star must be higher than the effective temperature for some wave-lengths, and less than the effective for others. The *brightness temperature* for any given wave-length is defined as that temperature at which a black body will radiate the same amount of energy per angstrom per unit area of surface at the wave-length concerned as is actually radiated by the star.

It may be noted in passing that since the energy emitted from a stellar atmosphere does not originate from a definite radiating surface, but is an integration of emissions at various depths, there is no concept corresponding to the "true temperature" of a surface emitting temperature radiation. There is no analogue in astrophysics to the statement that the brightness temperature is always less than the true.

If H_λ denotes the energy emitted at wave-length λ by a star, per unit wave-length per unit area of the stellar surface, then the brightness temperature T_λ is defined by the relation $4H_\lambda = B_\lambda(T_\lambda)$, where $B_\lambda(T)/c$ (c being the velocity of light) is the energy density per unit wave-length at wave-length λ of radiation in a constant temperature enclosure at temperature T and is given by Planck's formula. The effective temperature T_e is defined by $\frac{1}{4}acT_e^4 = H$, where $\frac{1}{4}ac$ is Stefan's constant and $H = \int_0^\infty H_\lambda d\lambda$ being thus the total energy emitted per unit area of surface. But the quantity ordinarily obtained from spectrophotometry of the continuous spectrum is the *colour temperature* T'_λ , which is defined as being the temperature of a black body for which the logarithmic derivative of the emitted radiation with respect to wave-length is the same as the corresponding logarithmic derivative for the actual star. Thus T'_λ is defined by

$$\frac{d}{d\lambda} \log H_\lambda = \left[\frac{d}{d\lambda} \log B_\lambda(T) \right]_{T=T'_\lambda}.$$

For a true black-body surface the brightness and colour temperatures at all wave-lengths are the same, each being equal to the effective temperature. For a star we have seen, from a consideration of the discontinuity at the Balmer limit, that the brightness temperature must be less than the effective at some wave-lengths and greater at others. A consideration of the general properties of the diagram described above shows that in general the slope of the logarithmic curve for the stellar radiation cannot be the same as that for the logarithmic curve of black-body radiation at the effective temperature of the star—that is to say, the colour temperature will not, in general, be the same as the effective. The general qualitative effect is very well illustrated by a diagram given by Pannekoek (*Ap. J.*, 84, 488), which is a theoretical diagram for the energy emitted by a star of effective temperature 10,080°. The diagram should not be regarded as quantitatively correct, as the theory used is based on some rather crude approximations (see section 4), but it does illustrate the general qualitative features which must be displayed for a star with a discontinuity of about 1.2 magnitudes in its continuous spectrum.

Although the continuous spectrum of an A0 star is not that of a black body, it is nevertheless true that over the visible spectral range (and possibly over the whole of that part of the spectrum which lies between the Balmer and Paschen series limits) the observed energy distribution can be represented by a Planck curve to an accuracy of a few per cent. This means that over the visible spectrum the radiation emitted per unit area of surface is approximately equal to a Planck function multiplied by a constant factor, and the colour temperature is thus approximately independent of wave-length, but from the foregoing it will be seen that it does *not* follow that the colour temperature can be identified with either the effective temperature or with the brightness temperatures

at wave-lengths lying within the spectral range for which a Planck curve gives a good fit to the observations. In view of the fact that attempts have been made to identify colour temperatures with brightness temperatures and so to deduce accurate measures of stellar diameters *, it is desirable to stress this. For a "black-body" star the spectral energy distribution is a Planck curve for *all* wave-lengths, and the colour and brightness temperatures for all wave-lengths are then equal to the effective, but an elementary qualitative study of Pannekoek's diagram shows that a good fit to a Planck curve over a *limited* wave-length range does not mean that the colour temperature throughout that range is to be identified (even approximately) with the brightness temperatures for the same range. In this respect an Ao star is to some extent analogous to an incandescent tungsten filament such as is used in an ordinary electric lamp. For example, a tungsten vacuum lamp with a true filament temperature of 2500° K. yields an energy distribution which, over the visible spectral range, fits a Planck curve to an accuracy of about 1 per cent. (see W. E. Forsythe, "Colour Match and Spectral Distribution," *J.O.S.A. and R.S.I.*, 7, 1115, 1923: Forsythe finds that there is an excess of about 1 per cent. in the green for such a lamp as compared with a black-body curve fitted to the blue and red). The colour temperature is thus approximately constant over the visible range, but from the values given by Forsythe and Worthing in a paper compiled in 1924 for the International Commission on Illumination, the colour temperature of such a lamp is 2554°, being in excess of the true temperature, whereas the brightness temperature at λ 6650 is as low as 2275°. One would clearly be in error in deducing that the filament behaved as a black body from the circumstance that its energy distribution over the visible range gives a good fit to the Planck curve for 2554°, and the same applies to an Ao star.†

It is easy to be wise after the event, but it must be recorded that after the appearance, in 1926, of Ch'ing Sung Yü's paper on the Balmer discontinuity, there was no excuse for believing that stars, and particularly Ao stars, behaved as black bodies. If this had been properly realised by those who were trying, in the years immediately following, to measure absolute colour temperatures, it would have saved us the perplexity that resulted when the observations for Ao stars persistently yielded colour temperatures heavily in excess of the Fowler-Milne value, which we believed at the time, in consequence of the black-body assumption, to be a good approximation to the effective and colour temperatures. As a consequence of this quite erroneous belief a large amount of time was spent in trying to track down and eliminate a hypothetical unknown source of observational error, and it was only slowly that the observers were forced to believe that their measures were substantially correct.

3. *Colour Temperature Observations.*—It is not proposed to include in the present note a detailed review of the technique involved in the measurement of colour temperatures. Full details are given in the publications of the various observatories concerned, and the spectrophotometric process follows well-understood lines. It will be sufficient, for the present purpose, to confine ourselves to general principles.

The concept of colour temperature has been defined in the previous section. The method now generally used is that of photographic spectrophotometry, and the final result of a spectrophotometric comparison of two sources of radiation is the difference between the corresponding values of a certain function of the colour temperature. If I_{λ_1} and I_{λ_2} are the amounts of energy per unit wave-length (or per unit frequency) received on the photographic plate from the two sources in question at wave-length λ , the spectrophotometric comparisons give determinations of the ratio $I_{\lambda_1}/I_{\lambda_2}$. From these determinations the quantity $\frac{d}{d(1/\lambda)} \log_e (I_{\lambda_1}/I_{\lambda_2})$ can be derived, and by an applica-

* It should be noticed that in formulæ, such as those given on p. 738 of Russell, Dugan and Stewart's *Astronomy*, which connect the diameter of a star with its "temperature", the "temperatures" are brightness temperatures.

† And to the Sun: see results quoted in section 3.

tion of Planck's formula it can be shown that this expression is equal to $\phi_\lambda(T'_2) - \phi_\lambda(T'_1)$, where T'_1 and T'_2 are the colour temperatures of the two sources of light at wave-length λ , and the function $\phi_\lambda(T)$ is given by the equation

$$\phi_\lambda(T) = \frac{c_2}{T} \left(1 - e^{-c_2/\lambda T} \right),$$

c_2 being a known physical constant ($= 14,320$ microns $\times$ degrees absolute).

For true black bodies $\log_e (I_{\lambda 1}/I_{\lambda 2})$ is very nearly a linear function of the reciprocal of the wave-length, and in such cases it would be convenient to extend the measures over a considerable range of wave-length and to deduce the value of $\phi_\lambda(T'_2) - \phi_\lambda(T'_1)$ by fitting a straight line to the measured values of the logarithmic light ratio (which is often expressed as a magnitude difference). The value of λ in the expression for $\phi_\lambda(T)$ may then be put equal to the harmonic mean value of the range of wave-length employed.

When actual stars are compared with laboratory black-body sources, or with each other, it is found that over considerable ranges of wave-length the plots of the logarithmic light ratio against reciprocal of wave-length are approximately linear. This means that over the wave-length ranges concerned the energy distribution of a star is approximately a Planck curve, a circumstance to which reference has been made in the preceding section. Under these conditions we proceed as in the case of black bodies, and the resulting colour temperatures may be taken to refer to the harmonic mean value of the

wave-length range. The values of $\frac{d}{d(1/\lambda)} \log_e (I_{\lambda 1}/I_{\lambda 2}) = \phi_\lambda(T'_2) - \phi_\lambda(T'_1)$ are known as gradient differences, following a very convenient nomenclature first introduced by Sampson.

Comparisons may be made between a star and a laboratory source, and if the latter has been standardized the corresponding value of $\phi_\lambda(T'_2)$ is known and so the value of $\phi_\lambda(T'_1)$ is obtained, and then the colour temperature T'_1 of the star can be computed. But comparisons may also be made between pairs of stars, and each such comparison gives the difference of the ϕ functions for the stars concerned. A series of such comparisons can be made to yield for each star the difference between the value of ϕ_λ for that star and the corresponding value for a definite standard star or for the mean of a particular set of standard stars. These differences are known as relative gradients and are usually given relative to the mean of certain stars of spectral type Ao. The relative gradients are then analogous to colour indices, a positive value indicating that the star concerned has a lower colour temperature than that for the zero-point of the scale (mean Ao).

For absolute observations, where comparison with a laboratory source is concerned, troublesome corrections for the effect of absorption and scattering in the Earth's atmosphere have to be determined and applied, and on account of this, and also on account of errors involved in the standardization of the laboratory sources used and of other errors attached to a distinctly difficult technique, the accuracy of an absolute comparison is much less than that of a relative one where the atmospheric effect can be eliminated by photographing the two stars at equal altitudes. In the opinion of the writer of the present note it is thus advisable to obtain a system of relative gradients first, and then to use each absolute comparison for the derivation of a single quantity, namely, the value of ϕ_λ corresponding to the zero-point (mean Ao) of the relative system. Colour temperatures can then be derived by adding the final value of ϕ_λ for the zero-point to the relative gradient for each star and using a conversion table for deriving the values of T' from the values of ϕ_λ . A conversion table for $\lambda = 5000$ A. is given in Table V, p. 63, of "Observations of Colour Temperatures of Stars, 1926-1932" (*Greenwich Publication*, 1932), and an extension of this table, together with tables for $\lambda = 4250$ and $\lambda = 3500$,

are given by Arnulf, Barbier, Chalonge and Canavaggia (*Journal des Observateurs*, 19, 152).*

The most extensive series of relative gradients so far published is the list of 250 gradients determined at Greenwich (*M.N.*, 100, 189). These were measured for wave-lengths covering the visible spectrum, and may be taken as referring to $\lambda = 5000$ Å. The average probable error of relative gradient is ± 0.02 . To derive values of $\phi(T')$ and so colour temperatures T' it is necessary to add the quantity ϕ_0 , where ϕ_0 is the value of ϕ corresponding to the zero-point of the Greenwich system, which was defined as the mean of 9 A0 stars. As has been explained above, the measurement of this quantity involves absolute comparisons of stars with a standardized lamp. The mean of two such series of measurements at Greenwich gave $\phi_0 = 0.99$ (Greaves, Davidson and Martin, *M.N.*, 94, 505), and using Greenwich relative gradients to reduce the measures of R. C. Williams at Ann Arbor (*Michigan Observatory Publications*, 7, No. 6) to the zero of the Greenwich system, a value of $\phi_0 = 1.23$ is obtained. In addition to these, Williams quotes a value of $\phi_0 = 1.01$ from the Göttingen absolute measurements, this value having been communicated privately by Professor Kienle. When the range of 0.24 of these three series of determinations is compared with the probable error of ± 0.02 for a Greenwich relative gradient, the difficulty of absolute as compared with relative colour temperature measurements, referred to previously, is emphasized. The errors in absolute measurements include, of course, any errors in the standardization of the lamps used, and Williams (*Michigan Observatory Publications*, 8, No. 2) has carried out the very desirable task of making a comparison between the standardizing laboratories concerned. If Williams's results are used to correct the astronomical determinations so as to refer them to the mean of the standardizing laboratories at Nela Park, Göttingen, Paris and Teddington (National Physical Laboratory), the values of ϕ_0 determined at Greenwich, Ann Arbor and Göttingen become 1.01, 1.03 and 1.27, the changes being insignificant. From the available data it would appear that if the value of $\phi_0 = 1.1$ (corresponding to a temperature of $15,600^\circ$) be used, it should be within about 0.1 of the true value. It may be noted that the temperature which was believed in 1925 to represent the A0 stars was $10,000^\circ$, corresponding to $\phi = 1.52$, and it is clear that the colour temperature of these stars considerably exceeds this.

If a zero-point of $\phi_0 = 1.10$ be used for converting the Greenwich relative gradients to colour temperatures, the highest colour temperature in the whole list of 250 stars is $28,000^\circ$ for the two stars γ Pegasi (B2) and β Cephei (B1). The mean relative gradient of the main sequence stars of type G0 in the Draper Catalogue is about 1.1 which, with $\phi_0 = 1.1$, gives $\phi = 2.2$, corresponding to a colour temperature of 6600° . The colour temperatures for the G0 giants are lower.†

It is natural to compare the result for the main sequence G0's with colour temperature observations for the Sun. The earlier measures of Wilsing and Abbot are not confined to the Sun's continuous spectrum alone, but include the effect of the absorption lines. In 1935 G. F. W. Mulders (*Zs. f. Ap.*, 11, 2, 132) applied his calibration of the Rowland intensity scale to the correction of Abbot's results for the effect of the lines. He also applied corrections to the spectrophotometric measures of H. H. Plaskett (*Publ. Dom. Astrophys. Obs.*, 2, 242), which were somewhat affected by absorption lines, but to a much smaller extent than Abbot's. The corrected results of both Abbot and Plaskett are in excellent agreement, and show that from $\lambda 4000$ to $\lambda 7000$ the spectral distribution for the centre of the disc is that of a Planck curve corresponding to a temperature of 7140° , so that this figure is the colour temperature for the centre of the disc over the whole of this spectral range. Below wave-length $\lambda 4000$

* The values appertaining to $\lambda 3500$ are quoted as referring to $\lambda 3750$, apparently owing to a typographical error.

† This remark applies only to the Draper classification (see section 6).

Mulders attempted to correct the measures of Fabry and Buisson (*C.R.*, 175, 156) extending over the spectral range λ 3000 to λ 4000, and obtained a colour temperature of 4850° . But for wave-lengths below λ 3850 no calibration of the Rowland scale was available and Mulders used the calibration for λ 3900, the ultra-violet results being thus comparatively uncertain. Measurements with a thermopile by Pettit (*Ap. J.*, 91, 159) have confirmed the high colour temperature for the Sun in the visible spectrum. Pettit's measures are made in blocks of 100 angstroms, and are subsequently corrected for the effect of absorption lines. From the data given it appears that over the wave-length range λ 4450 to λ 7000 the colour temperatures of the centre of the disc and of the integrated disc are not very different, being both near 7300° .* At λ 7000 the brightness temperatures are about 6000° for the centre and 5800° for the integrated disc, at λ 5500 the corresponding values are approximately 6300° and 6100° , and at λ 4500 they are approximately 6400° and 6200° . For shorter wave-lengths the brightness temperatures fall off considerably.

It thus appears that over the visible range of wave-length the colour temperature of the Sun's continuous spectrum is about 7200° for the centre of the disc. The value for the integrated disc would be expected to be about 2 per cent. less (this figure is based on Abbot's work) and may thus be put at about 7000° to 7100° . This is higher than the value (6600°) obtained at Greenwich for the main sequence Go's if the zero-point of $\phi_0 = 1.1$ be used, and this would appear to indicate that the value of ϕ_0 should be diminished and the whole system of colour temperatures raised. But with the dispersion used in the Greenwich work it is almost certain that at type Go the absorption lines are affecting the measures (no spectral types later than Go were included in the Greenwich programme for this reason). The Greenwich results for the Go stars thus probably require a correction which may be provisionally taken as being of the same order of magnitude as (but possibly somewhat greater than) the correction applied by Mulders to Plaskett's solar results. This correction consisted in the raising of the measured colour temperature by 300° (corresponding to a decrease in gradient of 0.09), and if it be applied to the Greenwich Go gradients, the value for the Sun (7000° to 7100°) now lies within the range of values for the main sequence Go stars. From this evidence, as far as it goes, there does not appear to be any serious inconsistency between stellar colour temperatures based on the zero-point $\phi_0 = 1.1$ and the solar measurements.

As will be emphasized later, data for the brightness temperatures and colour temperatures of the Sun are likely to be of high importance, and although the measurement is difficult it should be well worth while. What are required are good monochromatic measures † of the brightness temperatures at the centre of the disc and at various angular distances from the centre at all available wave-lengths. Such measurements would also give us the colour temperatures. In the meanwhile we note that the colour temperature of the Sun over the visible spectrum greatly exceeds the brightness temperatures in the same spectral range, and that the brightness temperatures decrease as we pass from the visible spectrum to the ultra-violet. The Sun, clearly, does not behave as a black body.

The measurements of stellar colour temperature referred to above were made over the visible range of spectrum. In addition we have a valuable series of measures by Arnulf, Barbier, Chalonge and others (*loc. cit.*: for a summary of results see *C.R.*, 210, 99). Besides their measures of the Balmer discontinuity, to which reference has

* The colour temperatures can be computed from the values given in the last two columns of Pettit's Table IV. The results are 7340° for the centre and 7270° for the integrated disc.

† The present writer, who is probably prejudiced on the point, feels that the methods of photographic spectrophotometry should be used. With a high dispersion, direct monochromatic measures of the continuous spectrum are possible, and subsequent correction for the effect of lines would then be unnecessary.

been made in section 2 above, the French observers have derived absolute gradients for the mean wave-lengths λ 4250 and λ 3500 which they denote by ϕ_1 and ϕ_2 , the ranges of measurement lying on either side of the Balmer series limit. For the average A0 star the colour temperatures found are $T'_{4250} = 16,500^\circ$ and $T'_{3500} = 10,500^\circ$. The importance of measures of this kind (particularly the colour temperatures for λ 3500) will be discussed later.

4. *Theoretical Developments.*—In building up a theory of the escape of radiation from a stellar atmosphere it is necessary to introduce hypotheses, the immediate aim being the testing of these by comparing the deductions we draw from them with observation. In the theory that has been elaborated during the last two decades three hypotheses are introduced, viz. (1) that the star is in a steady state; (2) that radiation is the mechanism by which energy is transferred from the interior to the surface, the effects of conduction and convection being ignored; and (3) that the emission of radiation by stellar material at temperature T (defined by the mean kinetic energy of the atoms and electrons) is, for all frequencies of the continuous spectrum, that which it would be if the material were in complete thermodynamical equilibrium at temperature T .

With the first of these hypotheses few will be disposed to quarrel. With regard to the second, convective transfer is an alternative possibility which has to be kept in mind. The third hypothesis is called the hypothesis of local thermodynamic equilibrium. Attempts have been made to justify it by a theoretical microscopic analysis (see Woolley, *M.N.*, 99, 478), but in the present state of knowledge it seems that its validity can really only be tested by experimental verification or otherwise of deductions based on it. It is certain that in the neighbourhood of absorption lines it ceases to be valid (see below), and it will clearly become necessary to examine the effect of the presence of spectral lines on the theory. But for the present, as a first approximation, we ignore this effect.

In its most general form the mathematical theory based on the above hypotheses is extremely complicated. But in considering the escape of radiation from a stellar atmosphere we are concerned with depths small in comparison with the radius of the star, and accordingly a useful approximation is introduced whereby the curvature of the surface is neglected. The hypothesis of steady state then leads to the *equation of radiative transfer*, which is

$$\cos \theta \frac{d\mathcal{J}_\nu(\theta)}{dz} = k_\nu \mathcal{J}_\nu(\theta) - j_\nu, \quad (\text{A})$$

where $\mathcal{J}_\nu(\theta) \frac{d\omega}{4\pi} d\nu$ is the flow of radiation between frequencies ν and $\nu + d\nu$ per square centimetre per second travelling in directions within a solid angle $d\omega$ at an inclination θ to the vertical, k_ν is the mass coefficient of absorption for frequency ν^* , j_ν is the emission in ergs per gramme per second, ρ is the density and $z = \int_x^0 \rho dx$, $-x$ being the depth below the surface.

The object of the theory is to determine j_ν as a function of z and then to evaluate $\mathcal{J}_\nu(\theta)$ for $z=0$ from equation (A), thus obtaining the radiation emitted from the star for all frequencies and inclinations. The hypothesis of local thermodynamic equilibrium is expressed mathematically by

$$j_\nu = k_\nu B_\nu, \quad (\text{B})$$

where B_ν/c (c being the velocity of light) is the energy density of radiation of frequency ν in a constant temperature enclosure at temperature T (T being the temperature of the stellar material at depth z), and is given by Planck's formula.

* The absorption coefficient must be defined so as to include the effect of emission stimulated by the radiation field, as has been pointed out by Rosseland (*Theoretical Astrophysics*, p. 107; see also Chandrasekhar, *An Introduction to the Study of Stellar Structure*, pp. 205–207).

Further the hypothesis of steady state, combined with the hypothesis that only radiative transfer is effective, gives the equation

$$\int_0^\infty j_\nu d\nu = \int_0^\infty k_\nu \mathcal{F}_\nu d\nu, \quad (C)$$

where $\mathcal{F}_\nu = \frac{1}{4\pi} \int \mathcal{F}_\nu(\theta) d\omega$ integrated over a sphere. $\mathcal{F}_\nu/c$ is the energy density at depth z of the radiation of frequency ν integrated over all directions θ .

The boundary condition to be imposed on the solution is that at $z=0$, $\mathcal{F}_\nu(\theta)=0$ for values of θ between 90° and 180° , there being no inflowing radiation at the boundary.

In general, the absorption coefficient k_ν is a function of ν and of the temperature T , and the problem has so far proved to be extremely difficult (see below). But when k_ν is independent of the frequency ν the analysis is more tractable, and Milne (*M.N.*, **81**, 361) obtained his well-known approximation for T , viz.

$$acT^4 = H(2 + 3\tau),$$

where H is the net outward flux of radiation, integrated over all frequencies, per sq. cm. of surface per second, $\frac{1}{4}ac$ is Stefan's constant and $\tau = \int_0^z k dz$, k being the value of k_ν for all ν . If T_e be the *effective temperature* of the star, then $acT_e^4 = 4H$, and we get $T^4 = T_e^4(\frac{1}{2} + \frac{3}{4}\tau)$. The quantity τ , which was introduced by Milne, is called the optical depth. It has been shown that when values of T calculated from this formula are used to derive j_ν as a function of τ and then equation (A) is integrated so as to obtain values of $\mathcal{F}_\nu(\theta)$ at the boundary, the approximation so obtained is a very good one. Second approximations have been obtained by Jeans, Milne himself and Eddington (*The Internal Constitution of the Stars*, p. 332), and the whole problem of k_ν independent of frequency has been rigorously investigated by Hopf (*Mathematical Problems of Radiative Equilibrium*, Cambridge Tracts in Mathematics and Mathematical Physics, No. 31).

It is found that the assumption that the absorption coefficient is independent of frequency leads to the conclusion that although the distribution with frequency of the radiation emitted by the star is not quite the same as we should obtain by substituting the effective temperature T_e of the star in Planck's formula, the difference is not very great. The calculated distribution is, in fact, very similar to that given by the Planck formula, but the whole curve is shifted towards the region of higher frequencies, the shift of the maximum being only about 3 per cent. (see Milne, *M.N.*, **81**, 382). In other words, the star as a whole behaves very much as a black body. But as real stars do not do this, it follows that if we are to keep our original hypotheses, we must abandon the assumption that k_ν is independent of ν . In fact, the existence of the discontinuity at the Balmer limit will compel us to do this for the stars of types B and A on any plausible hypothesis.

It should be noticed at this point that the original development of the theory led to a result which, when compared with observation, actually did seem to confirm the assumption that the absorption coefficient was independent of frequency. The values of the emergent radiation can be calculated from the equation of transfer for any inclination θ to the normal to the surface, this being in fact the primary result of the solution, the total emergent radiation being then obtained by integration with respect to θ . By considering the solutions for $\theta=0$ and $\theta=90^\circ$, Milne (*Phil. Trans.*, A, **223**, 201) obtained expressions for the contrast at any assigned wave-length between the centre and limb of the stellar disc, and on putting in the effective temperature of the Sun, values were obtained for the centre-limb contrast which were in good agreement with the measurements of Abbot. Presumably any variation of k_ν with ν would upset this agreement, and the conclusion to be drawn is that k_ν is independent of ν and the Sun

behaves approximately as a black body. But the observational evidence summarized in the previous section shows that the Sun is nothing of the kind, and we here must face the possibility that our fundamental hypotheses of radiative transfer and local thermodynamic equilibrium are leading to incorrect results and require reconsideration. This matter will be further discussed presently.

Before reviewing the possible further development of the theory so as to treat the general case in which the absorption coefficient k_ν varies with the frequency ν , it should be noticed that on the assumption that k_ν is independent of ν , equations (B) and (C) lead to $\mathcal{J} = B$, where $\mathcal{J} = \int_0^\infty \mathcal{J}_\nu d\nu$ and $B = \int_0^\infty B_\nu d\nu$. This means that at any depth the effective temperature of the radiation is equal to the temperature of the stellar matter, so that the matter is in a kind of integrated equilibrium with the radiation field, in addition to being, by hypothesis, in the condition we have described as local thermodynamic equilibrium. It is thus not surprising, on general physical grounds, that the star as a whole should behave approximately as a black body. But for the case of actual stars where k_ν varies with ν it is not true that $\mathcal{J} = B$, and the effective temperature of the radiation at any depth is not equal to the temperature of the stellar matter.*

Coming now to the general case in which k_ν varies with frequency, it must be stated that the mathematical problem has so far proved very intractable. To make any progress at all, investigators have been compelled to use Eddington's approximation $K_\nu = \frac{1}{3}\mathcal{J}_\nu$, where $K_\nu = \frac{1}{4\pi} \int \mathcal{J}_\nu(\theta) \cos^2 \theta d\omega$ integrated over a sphere. This approximation has proved very useful in investigating line profile problems, but it is somewhat difficult to state the order of magnitude of the error involved in using it. In the problem of spectral energy distribution we have to aim at rather high accuracy, and although the approximation can be justified on general physical grounds (see Eddington, *The Internal Constitution of the Stars*, 322), there must remain some doubt as to whether it will yield results comparable to the accuracy of the observational evidence. But unfortunately it has so far proved necessary to introduce yet another approximation, namely, that the quantity B_ν varies linearly with a mean optical depth $\bar{\tau}$, the latter being defined by $\bar{\tau} = \int_0^\infty \bar{k} dz$, where $\bar{k}$ is a "mean value" of the k_ν defined by the relation

$$\frac{1}{\bar{k}} \int_0^\infty \frac{dB_\nu}{dT} d\nu = \int_0^\infty \frac{1}{k_\nu} \frac{dB_\nu}{dT} d\nu,$$

so that $\bar{k}$ is a weighted harmonic mean of the k_ν (known as the Rosseland mean). By assuming that B_ν is a linear function of $\bar{\tau}$, Milne (*Phil. Trans.*, A, 228, 431) showed that his original approximation $T^4 = T_e^4(\frac{1}{2} + \frac{3}{4}\tau)$ † could still be used provided $\bar{\tau}$ was substituted for τ . This result is sometimes quoted as being a particular case of the theorem of the Rosseland mean. Since the approximation that B_ν varies linearly with $\bar{\tau}$ is obviously very crude, it seems clear that no quantitative reliance can be placed on results obtained by invoking it, and the most that can be hoped from the theorem of the Rosseland mean is that it will lead us to a rough qualitative picture of what can happen.

In fact, Rosseland originally introduced his mean opacity $\bar{k}$ in connection with problems appertaining to the interiors of stars, where we may treat $\mathcal{J}_\nu$ as being practically identical with B_ν . It is not to be expected that the mean would have the same value

* For further discussion of this point see *Observatory*, 62, 266.

† The value of this approximation in the case k_ν independent of ν arises from the fact that it gives a temperature distribution such that if it is substituted in the equation of transfer, the integration of the latter gives the correct outward flux of radiation at the boundary. It is easy to show that a similarly good approximation in the general case would be $T^4 = T_e^4(\alpha + \frac{3}{4}\bar{\tau})$, where α is to be so chosen as to give the correct flux at the boundary. The approximations $K_\nu = \frac{1}{3}\mathcal{J}_\nu$ and $B_\nu = a_\nu + b_\nu \bar{\tau}$ lead to the value $\frac{1}{3}$ for α , and this must be regarded as a crude approximation.

in investigations dealing with stellar atmospheres, and the fallacy of regarding the theorem of the Rosseland mean as an accurate result in stellar atmosphere work has been explicitly pointed out by Krock (*M.N.*, **98**, 205).

It is necessary to state that if the Rosseland mean theorem is invoked as an approximation, it should only be used to derive the temperature T as a function of mean optical depth, and the emergent radiation should then be calculated by integration of the equation of transfer. Unfortunately in some investigations the approximation that B_ν is a linear function of τ has been used to derive the emergent radiation directly instead of being confined to the derivation of the temperature. It seems to the present writer that little quantitative reliance can be placed on results obtained in this way.

If we are to develop a rational theory which is to be used for the purpose of checking the original hypotheses, and which, if proved by comparison with observation, can be invoked to deduce the temperature distribution in the atmosphere of a star from observations of the star's colour temperature (which is the only available observation for most stars), it seems evident that the mathematical difficulties will have to be overcome before real progress is possible. The analytical problem of solving the equations will be difficult and remains at present a challenge to theoretical astrophysicists, but until it is overcome it must be admitted that the road to progress is barred.

But even if a satisfactory analytical treatment be developed it will be necessary, before it is applied, to know the values of the absorption coefficient for different frequencies. This involves a knowledge of the relative abundance of the chemical elements in stellar atmospheres and the absorption coefficient of each element for any assigned wave-length. The first of these has been the subject of an important investigation by Russell (*Ap. J.*, **70**, 11), who has studied the problem in the case of the Sun, and it is not, in the present state of knowledge, an unreasonable assumption to suppose that Russell's representative composition (see also *Ap. J.*, **75**, 339 *) is applicable to the stars. But as regards absorption coefficients the present position does not give us any grounds for optimism as regards the prospects of elaborating in the near future a detailed numerical theory of the escape of radiation from a stellar atmosphere. The position of our knowledge of absorption coefficients up to about the end of 1938 has been summarized by Page in a R.A.S. Council Report (*M.N.*, **99**, 385), and it is pointed out that the experimental results available are, in general, marked by considerable disagreement, both internally and as compared with theoretical predictions. The methods of wave mechanics have confirmed the essential accuracy of the original method of Kramers (which was based on the Bohr model of the atom and the correspondence principle) as far as hydrogen atoms and hydrogenic atoms (such as He^+ , Li^{++} and other atoms consisting of a single electron and a tightly packed nucleus) are concerned, and experiment seems to agree with this conclusion. But modern theoretical and experimental research does not support the attempts that have been made to extend the Kramers method to other atoms. And although formulæ based on wave mechanics and applicable only to the ground states of univalent elements in the alkali group succeed in predicting the order of magnitude of the observed absorption, they seem to fail with regard to the variation of absorption with wave-length.†

In addition to the contribution made to the total absorption coefficient by the neutral and ionized chemical elements, it has been pointed out by Wildt (*Ap. J.*, **89**, 295, **90**, 611, and **93**, 47) that attention must be paid to negative hydrogen ions which, for stars of medium and late spectral type, may contribute materially to the total value of

* The ratio of hydrogen atoms to metallic atoms is given in this paper as 61.5. But in a subsequent investigation Russell arrives at the conclusion that hydrogen is about a thousand times as abundant as all the metals together. See *Ap. J.*, **78**, 281.

† But it must not be assumed that the theoretical calculations have reached finality. P. R. Bates (*M.N.*, **100**, 25) has recently given calculations for the atoms from boron to neon, and the variation of his calculated absorption with frequency is quite different from that given by previous approximations.

k_ν . A theory of the continuous absorption provided by such ions has recently been developed by Massey and Bates (*Ap. J.*, 91, 202).

It thus seems that there are two bars to progress, namely, the serious lack of knowledge of absorption coefficients, and the various mathematical difficulties in the further development of the theory of radiative equilibrium. As regards the attempts that have been made to calculate the spectral energy distribution of stars, they have been based on crude mathematical approximations and on attempts to extend the Kramers method of calculation of absorption coefficients. We cannot therefore expect quantitative accuracy. If we accept existing calculations of absorption coefficients as being roughly qualitatively true, it appears that whereas the hydrogen absorption coefficient increases with increasing wave-length between the various series limits, the total contribution by the metals in the visible spectral range decreases with increasing wave-length for the later type stars.

At the hydrogen series limits themselves there is a discontinuity in the absorption coefficient leading to a discontinuity in the continuous spectrum. As has been pointed out in section 2 of the present note, elementary considerations show that as a consequence of such discontinuities it follows that the colour temperatures and brightness temperatures of a star differ in general from the effective temperature and from each other. The variation of k_ν between the series limits leads independently to a similar state of affairs.

For the early type stars the hydrogen contribution to the total absorption coefficient predominates and for the late types the effect of the metals is preponderant. It seems possible that for some spectral type there may be a rough balance between the hydrogen and metallic contributions, and it has been suggested that this actually happens at about spectral type G0, so that for the Sun we can treat k_ν as independent of ν throughout the spectral range between the Balmer and Paschen limits. Since most of the energy output of the Sun lies in this range, it is thus suggested that the calculations which have been made for the model k_ν independent of ν are approximately true for the solar spectrum.

So far it has been assumed that the effect of absorption lines can be neglected. But before any theory can be said to be fully developed, it is necessary to consider those spectral regions for which the equation of local thermodynamic equilibrium must cease to be true, and for which monochromatic scattering becomes important. A beginning has been made by Chandrasekhar (*M.N.*, 96, 21), who treats the case in which, apart from regions affected by lines, k_ν is independent of ν and local thermodynamic equilibrium holds. But for wave-lengths near a spectral line monochromatic scattering and increased absorption are taken into account. Chandrasekhar assumes that the lines are uniformly distributed over the whole spectral range, and his analysis proceeds on the basis of the approximation $K_\nu = \frac{1}{3} \mathcal{J}_\nu$. From his results it appears that for the Sun with effective temperature $T_e = 5740^\circ$ the effect of the lines is to increase the colour temperature for the visible range of spectrum. By adopting the value $0.2d\nu$ for the probability that the frequency interval $(\nu, \nu + d\nu)$ will include an absorption line, and assuming appropriate values for the other parameters involved, it is possible to obtain a calculated colour temperature of about 6700° for the spectral range $\lambda 4157$ to $\lambda 6235$, but this is achieved at the cost of making the calculated centre-limb contrasts disagree with the observed. By choosing other values of the parameters corresponding to the model of a purely scattering atmosphere placed above material in pure local thermodynamic equilibrium, it is found that good agreement with the observed centre-limb contrasts can be obtained with a colour temperature of about 6500° .* But the observed colour temperature appears, as has been remarked in the previous section of the present note, to exceed 7000° . However, we must not necessarily conclude from this that there is a disagreement between theory and observation of such a nature as to cause us to deduce

* The value of 6350, given on p. 41 of Chandrasekhar's paper, has here been increased in accordance with the note on p. 42.

that one or both of our original hypotheses (radiative transfer and local thermodynamic equilibrium) are in error. Chandrasekhar's treatment assumes k_ν independent of ν for continuous spectrum frequencies, and it may very well be possible to secure agreement with the observed centre-limb contrasts and colour temperatures by introducing an appropriate variation of k_ν with frequency combined with suitable parameters for the formation of the absorption lines. It seems appropriate at this stage to remark that the hypothesis of radiative transfer has been questioned by H. H. Plaskett (*M.N.*, 96, 402) who, from a comparison of the centre-limb contrasts measured by Moll, Burger and van der Bilt (*B.A.N.*, 3, 83) with calculated values, deduces a temperature distribution with optical depth which differs from that given by the radiative equilibrium theory. Plaskett deduces from this and from an observational study of solar granulation that convective transfer of energy is effective in a zone of instability whose upper surface occurs near optical depth $\tau=1$. But, as has been pointed out by Woolley (*Observatory*, 62, 296), Plaskett's calculated values are based on the assumption that the absorption coefficient is independent of wave-length. This may not be the case, and, as far as this is concerned, it would thus be premature to accept Plaskett's quantitative conclusions, but the presence of granulation certainly does suggest a zone of convective instability. The question is still unsettled as to whether convection will seriously modify the conclusions of a developed radiative equilibrium theory. In the meanwhile it may not be unprofitable to study the consequences of convective transfer, and reference should be made to a recent paper by Thackeray (*M.N.*, 100, 614), who deduces the consequences of assuming that the solar atmosphere is in full convective equilibrium with a ratio of specific heats equal to $4/3$. Thackeray further assumes that the absorption coefficient is independent of the frequency and proportional to the pressure. On these assumptions it is found that the values of the centre-limb contrast and the distribution of energy in the continuous spectrum are very similar to the results predicted by the radiative equilibrium theory for k_ν independent of ν . The wave-length of maximum intensity is further to the violet in the case of convective equilibrium. But it should be pointed out that owing to Thackeray's assumption that k_ν is independent of ν (this assumption is implicit in the analysis), considerable caution should be exercised in attempting to apply the deduced results to real stars. It is nevertheless interesting to have a comparison of the two forms of equilibrium for a simple, if not an actual, case.

The conclusion seems to be that substantial progress must await good determinations of absorption coefficients which, combined with knowledge of the relative abundance of the elements, will give the total stellar absorption coefficient for various frequencies, and, as has been explained, the subsequent development of the radiative equilibrium theory will involve the overcoming of very serious mathematical difficulties. If such a fully developed theory were to satisfy the observational tests that are possible, we could then use the theory to deduce from the observed colour temperatures of stars the actual physical surface temperatures, and the variation of temperature with depth. But we must be prepared for the possibility that the theory will not satisfy observational checks and that the original hypotheses on which it is based must be modified. Convective transfer may turn out to play an important part.

5. *Observational Tests of Theory.*—The full development of a theory based on the hypotheses of radiative transfer and local thermodynamical equilibrium is held up for the time being on account of the difficulties referred to in the foregoing. For the present it is on observational inquiry alone that we have to rely for the extension of our knowledge. It is highly probable that the activities of observers will be most usefully employed if attention is concentrated on the observational tests to which the predictions of any fully developed theory will have to be subjected, and by which the hypotheses of the theory must finally be judged. For the majority of stars there seem to be only two observational tests available, viz.:

- (a) The comparison, for the same star, of the difference between colour temperatures derived from measures over different spectral ranges with the difference predicted by theory;
- (b) The comparison of the measured discontinuities at series limits, such as the Balmer limit, with theoretically calculated discontinuities.

These two tests taken together amount to the full comparison between the observed and calculated spectral energy distributions of stars over all accessible wave-lengths. It is, however, convenient to treat them separately. As regards (a), material already exists in the shape of colour temperatures measured over the visible spectral range and over the spectral regions on either side of the Balmer series limit. It is in this connection that observations such as those carried out in recent years by Arnulf, Barbier, Chalonge and others (*loc. cit.*) are likely to be of great importance. The present position as regards the stars of types A and B seems to be that the colour temperature does not vary heavily with wave-length over the whole spectral range between λ 3900 and λ 6500. Within the errors of observation the colour temperatures at λ 4250 (determined by the French observers) agree with the results from the visible range, and as regards the visible spectral range itself, the measures at Greenwich * (*M.N.*, 94, 506, 507), Göttingen (*Ergeb. d. Exakt. Naturw.*, 16, 445; for misprints see Williams, *Michigan Obs. Publ.*, 7, No. 4, 123) and Ann Arbor (*Michigan Obs. Publ.*, 7, No. 6, 151 *et seq.*) have given deviations from the Planck curves of best fit which do not agree among themselves and which, in view of the probable errors involved, cannot be regarded as significant.† It is possible that future observational refinement will reveal small but real deviations. From the available measurements it seems safe to say that the deviations are less than 5 per cent.

As regards (b), the measures of Arnulf, Barbier, Chalonge and others provide a useful source of information for the Balmer discontinuity, to which reference has previously been made. The attempt to derive absorption coefficients by an extension of the Kramers method (which is now known to be unsound, as has been stated in the previous section) leads to the prediction of discontinuities for elements other than hydrogen which have not been found observationally (see Pannekoek, *Publ. Astron. Inst. Amsterdam*, No. 4, p. 27).

A more detailed comparison between theory and observation is possible in the case of the Sun, for which brightness temperatures can be measured at the centre of the disc and at various angular distances from the centre, the colour temperatures then being derived as a by-product. Good monochromatic measures of the Sun's brightness temperature at all available wave-lengths are thus of high value. For other stars brightness temperatures for the integrated disc are obtainable if the angular semi-diameter of the star be known, in addition to the monochromatic magnitude of the star and the monochromatic magnitude of the Sun. It should be possible to obtain the necessary data for eclipsing binaries, but it is necessary to know the parallaxes in order to obtain the angular diameters. The problem is complicated by the circumstance that the observation of the ratio of the radius of the stellar diameter to the radius of the orbit is affected by the assumed law of darkening from the centre of the disc to the limb, and this law of darkening can itself only be derived from a completed theory. For the star β Aurigæ (Ao) the brightness temperatures (which are the same for the two components)

* There seems to have been some misunderstanding about these measures (see R. C. Williams, *Michigan Obs. Publ.*, 7, No. 4, 123) in the reduction of which a linear gradient of atmospheric absorption with reciprocal of wave-length was *not* assumed. As explained in *M.N.*, 94, 505 and 506, the residuals at λ 5300 for the comparisons between the stars and the standard lamps were corrected by the residuals from the linear gradient obtained from the measurements of atmospheric reddening.

† We are here concerned with *absolute* comparisons with laboratory standards, and, as has been stated previously, the observational errors are much higher than for relative comparisons.

at the effective wave-length of visual light have been calculated for the extreme suppositions of uniform disc and completely darkened limb, and the respective values obtained are $10,100^\circ$ and 9630° .^{*} It should be observed that these values are derived not from monochromatic magnitudes, but from ordinary visual magnitudes, and would presumably require correction for the effect of line integration to obtain true brightness temperatures appertaining to the continuous spectrum. The calculation assumes a brightness temperature of 6000° for the Sun, the Sun's apparent visual magnitude is taken as -26.72 , the apparent visual magnitude of each component as 2.82 , and Shapley's values (*Ap. J.*, **38**, 169) for the radius are used. The weakest point is probably the parallax (taken as $0''.039$), but the brightness temperature for $\lambda 5300$ for this star appears to be in the neighbourhood of $10,000^\circ$. S. Gaposchkin (*A.N.*, **248**, 214) has given results for various eclipsing binaries which suggest a scale of brightness temperatures for the effective wave-length of visual light ranging from $28,000^\circ$ for O8 through $18,500^\circ$ for B0, and $11,000^\circ$ for A0 to 5500° for G0, 3900° for K0 and 3700° for M1. It would be very desirable to have strictly monochromatic brightness temperatures of this kind for wave-lengths in the continuous spectrum.

Other results of value which could come out of a careful spectrophotometric survey of eclipsing binaries would be data as to the variation of brightness temperature over the disc for various wave-lengths. In the meanwhile very interesting results for Algol have been given by Barbier and Chalonge (*Observatory*, **62**, 273), who find that whereas the colour temperature at $\lambda 4250$ appears to vary during eclipse, the colour temperature at $\lambda 3500$ suffers no appreciable change, indicating that for wave-lengths just shorter than that of the Balmer series limit the colour temperature is largely independent of the angle of emergence.

This leads to an interesting interpretation. If for a restricted range of wave-length the absorption coefficient is very much larger than the Rosseland mean coefficient for all wave-lengths[†], then the hypothesis of local thermodynamic equilibrium leads to the conclusion that the colour temperature is independent of the angle of emergence and is equal to the true temperature of the surface. The absorption coefficient increases suddenly as we pass to the short wave-length side of the Balmer series limit, and Barbier and Chalonge thus conclude that the colour temperature found for Algol from measures at wave-lengths less than the Balmer series limit is not far from being the surface temperature. It seems legitimate to infer that the same will be true for all stars for which the Balmer discontinuity is greater than for Algol. Such stars range from spectral types B8 to A5, and from the published measures by their co-workers and themselves, Barbier and Chalonge conclude that the surface temperatures of stars near type A0 range from $14,000^\circ$ for B8 through $10,500^\circ$ for A0 to 9500° for A5. This deduction of course is based on the hypothesis of local thermodynamic equilibrium, but it is obviously of importance, and it becomes highly desirable to obtain as accurate measurements as possible of the variation of the colour temperature of Algol and other eclipsing binaries for wave-lengths on either side of the Balmer limit. It would be preferable to employ the relative method and compare the eclipsing binary with another star, eliminating atmospheric reddening by equal altitude comparisons.

It may be noticed at this point that the neglect of curvature becomes unjustifiable at or near the limb, where $\theta = 90^\circ$ in the notation of section 4. But integration of the

^{*} These values are the effective temperatures obtained by applying corrections from visual to bolometric magnitude on the assumption that the star radiates as a black body. This means that they are really brightness temperatures for the effective wave-length of visual light.

[†] This condition is not explicitly stated by Barbier and Chalonge. If it is satisfied, then it follows that the temperature gradient with respect to the optical depths τ_ν for the frequencies in question ($\tau_\nu = \int_0^2 k_\nu dz$ in the notation of section 4) is small. By integration of the equation of transfer, using τ_ν as the independent variable, it is found that under these conditions $\mathcal{J}_\nu(\theta)$ is approximately equal to B_ν at the surface.

modified equation of transfer shows that, provided thermodynamic equilibrium holds at the surface, $\mathcal{J}_\nu(\theta) = B_\nu$ at the limb. This means that at the limb the colour and brightness temperatures are the same for all wave-lengths, and the Balmer discontinuity disappears. This conclusion depends on the assumption that local thermodynamic equilibrium holds at the surface, and careful spectrophotometric observations of the Sun's limb and of eclipsing binaries which undergo nearly total eclipses should be capable of giving decisive evidence with regard to this. It is interesting to note that in the case of Algol, for which eclipses are far from being total, Barbier and Chalonge (*Annales d'Astrophysique*, 1, 387) find some evidence for a small diminution in the Balmer discontinuity during eclipse. More investigations of this kind are required.

Brightness temperatures can also be inferred for late-type giants whose angular diameters can be measured with the interferometer (the law of darkening towards the limb being again a complication as it affects the measurement of diameter). As in the case of eclipsing binaries, the brightness temperatures which can be deduced from existing data are not monochromatic and apply to the effective wave-length of visual light. The results range from 4300° for α Boötis (K0) through 3100° for α Scorpii (M0) to 2650° for α Herculis (M8) and 2400° for Mira Ceti at maximum. (See Russell, Dugan and Stewart, *Astronomy*, 749.)

The present position seems to be that it would be highly desirable if observational attention were concentrated on the measurement of monochromatic brightness temperatures over the solar disc, the measurement of the monochromatic differences of magnitude between the Sun, eclipsing binaries and stars for which interferometer measures of diameter are available, and on careful spectrophotometric measures of colour temperature of eclipsing binaries, including the spectral region to the short wave-length side of the Balmer limit. Parallax observers can make a useful contribution by devoting attention to eclipsing binaries, and β Aurigæ would seem to merit special consideration, as has been pointed out by Pannekoek (*Ap. J.*, 84, 506). It would also be very desirable to push forward with general colour temperature work, which should include measures near λ 3500 whenever observers are fortunate enough to have a suitable mountain site at their disposal.

6. *Results obtained from Relative Gradients.*—We now turn to a brief survey of investigations which are based on a study of relative gradients. As explained in section 3 above, the measurement of relative gradients can be performed with a degree of accuracy which is not possible in the case of absolute comparisons with standardized lamps.

The only extensive list of relative spectrophotometric gradients so far available is the list of results for 250 stars measured at Greenwich over the visible range of spectrum (*M.N.*, 100, 189). It should be noticed in the first place that these gradients are similar to colour indices in that they are essentially the difference between the red and blue monochromatic magnitudes of a star. But the important difference between gradients and colour indices lies in the fact that gradients are determined from monochromatic measurements confined to the continuous spectrum, whereas colour indices are based on ordinary heterochromatic magnitude measurements, and heterochromatic magnitudes necessarily include the effect of absorption lines in the spectral range involved. This means that whereas spectrophotometric gradients are an expression of the distribution of energy in the continuous spectrum of a star, colour indices are a composite expression of the continuous spectral distribution and of the integrated intensities of all involved spectral lines. The extent to which colour indices are affected by lines can be ascertained by a comparison with gradients, and the Greenwich material is sufficiently extensive over types O to G to allow of such.

A comparison between the Greenwich gradients and various systems of colour index has been made by Atkinson, Hunter and Martin (*M.N.*, 100, 196), and it is evident from their work that the contribution made to colour index by spectral lines is by no means negligible. Thus for the same value of the gradient the colour indices of stars

on Elvey's system (*Ap. J.*, 74, 298) may differ by about 0^m.5, it being probable that the greater part of this is to be ascribed to the variation in line intensity in the ultra-violet. In this spectral region the Balmer lines (and the Balmer discontinuity) are very strong in A0 stars, and consequently there is a large difference in colour index between a normal A0 star and a "reddened" (see below) early B-type star of the same gradient. There is also a difference in colour index between stars of the same gradient and spectral type but of different hydrogen-line intensity, c stars having a lower colour index. The range in colour index for stars of the same gradient is naturally smaller when the colour indices are derived from measures which are not so heavily influenced by ultra-violet lines, as is the case when photographic magnitudes determined with a refractor are differenced against visual magnitudes, but the comparison of the Greenwich gradients with colour indices of this kind shows that the effect is still appreciable. The investigation makes it clear that colour index must not be regarded as a measure of the colour temperature of a star.

Turning now to the relationship between colour temperature and spectral type, a comparison between the Greenwich gradients and the spectral types of the Henry Draper Catalogue shows a heavy range in gradient for the type G0 stars and for the stars of types B0 to B2; for A0 stars the scatter in gradient is much less. But if the Mount Wilson spectral classification be used, the scatter in gradient is considerably reduced for the G0 stars and enhanced for the stars of type A0.

As far as the type G0 stars are concerned, the scatter in gradient is connected with absolute magnitude, the giant stars being of lower colour temperature than those belonging to the main sequence. It has often been stated in the past that this is in accordance with theoretical prediction, but the circumstance that the absolute magnitude effect practically disappears at G0 when the Mount Wilson classification is used indicates that the statement, frequently made, that for stars of the same spectral type the giant stars are the redder, must be treated with caution. This conclusion was originally drawn from colour-index data, and we have just seen that colour indices do not involve colour temperature alone, but that the intensities of spectral lines play an important part in determining the colour index of a star. But line intensities are known to be correlated with absolute magnitude for stars of the same spectral type, and it would thus be rash to draw general conclusions from the evidence of colour indices. As regards the predictions of theory, the correct theoretical result is that *if spectral type be taken to correspond to the state of ionisation with regard to an assigned ionization potential**, then for stars of the same spectral type the *average temperature of the reversing layer* will decrease with increasing luminosity. But the average temperature of the reversing layer of a star cannot be assumed to be proportional to the colour temperature, and the difference in the observational results when H.D. and Mount Wilson types are used † reminds us that caution must be exercised in identifying existing classifications with a theoretically ideal system. The conclusion is that any statement as to the relationship between colour temperature and absolute magnitude for stars of the same spectral type is meaningless unless the spectral classification be specified, and the physical meaning of any such relationship is complex, depending on the interpretation of the systems of classification used in practice.

There is a heavy scatter in gradient for stars of types B0 to B2, some of these stars being comparable in colour temperature to the G0 stars. Early B-type stars of low colour temperature are often referred to as "yellow B-type stars," and no positive statement can yet be made as to whether they are really of high colour temperature, the light being reddened by scattering in interstellar space, or whether the observed

* Milne (*M.N.*, 85, 783) uses an ionization potential of 8 volts for G0 stars.

† For type A stars it was pointed out in 1930 by Miss E. T. R. Williams (*H.C.*, 348) that the Henry Draper classification was approximately a temperature classification, the absolute magnitude effect being absent, and that for the Mount Wilson spectral types there was a marked difference in colour temperature between the "n" and "s" subdivisions of the same spectral type, the "n" stars of a given spectral class being decidedly cooler.

spectral energy distributions are intrinsic to the stars themselves. On the one hand, the gradients seem to be correlated with the intensity of the interstellar K line, which may be taken as a measure of distance, and on the other there seems to be a marked tendency for the gradients of those early B-type stars whose spectra exhibit emission lines to be of low colour temperature as compared with stars characterized by absorption spectral lines. Further, with observations limited to the brighter apparent magnitudes, it is difficult to say whether the correlation between gradient and distance is a true distance effect, or whether it is really an absolute magnitude effect which appears statistically as a spurious distance effect owing to the limitation of the data in apparent magnitude.* It is possible that both space reddening and intrinsically low colour temperatures are involved.

The subject is a large one and cannot be adequately reviewed within the scope of the present note. It must suffice to say that as in the case of the variation, or otherwise, of colour temperature with absolute magnitude for stars of the same spectral type, investigations based on colour indices must be treated with reserve. Atkinson, Hunter and Martin (*M.N.*, 100, 203) have pointed out that some stars which would be called "reddened" on the basis of Elvey's colour indices are of quite normal gradient, the apparent reddening being due to the effect of spectral lines. The problem can only be really satisfactorily attacked with the aid of spectrophotometric gradients, which are based on monochromatic measures of the continuous spectrum, and the extension of relative gradient work to stars fainter than apparent magnitude 5.0 is greatly to be desired. In the meanwhile reference should be made to the work of E. G. Williams (*Ap. J.*, 79, 280) and to a recent paper by Hunter and Martin (*M.N.*, 100, 669). The space-reddening coefficients appear to vary with galactic longitude, and, in addition to an apparent correlation with distance, reddening seems to be connected with obscuration by local absorbing clouds or nebulae and with the appearance of "e" and "c" characteristics in the spectra.

7. *Conclusion.*—The object of this note has been to outline the present position of an interesting but difficult subject, and the developments which have led up to it. No attempt has been made to include a complete list of references, and it is inevitable that many published researches, especially those of a specialized nature, should not have been mentioned.

It is rather unfortunate that for the majority of the stars the spectral energy distribution is all that can be observed. Brightness temperatures are of more immediate physical interest than colour temperatures, but it is to the latter that we must, for the main part, turn. The deduction of the physical state of a stellar atmosphere from the spectral energy distribution—that is, from the colour temperature and discontinuity measures—requires the aid of a fully developed and adequately checked theory, and if the observational tests outlined in section 5 above were satisfied by a developed theory, it would probably be regarded as reliable. From what has been said it seems to be evident that there is still plenty of work for the observer, but on the whole it is by the mathematician and the mathematical physicist that the immediate major advance must be made. The mathematical development of the existing theory in the general case of variable absorption coefficient, and the numerical calculation of the absorption coefficient itself, are tasks that must be mastered if real progress is to be achieved. The work of the last decade has at any rate led us to a clearer understanding of what are the problems involved, and it must be admitted that they are difficult.

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Royal Observatory, Edinburgh:
1941 March.

* For stars of the same apparent magnitude the more distant stars are the stars of higher luminosity. True absolute magnitude and distance effects cannot be separated unless the range of the data in apparent magnitude is sufficiently great.

SOLAR ACTIVITY

Sunspots.—Sunspot frequency during 1940 declined 25 per cent. as compared with the preceding year. The sunspot “number” for 1940, based on Greenwich data alone, is provisionally 66, the international values published from Zürich for the preceding years, 1936–1939, being 80, 114, 110 and 89. In spite of the lessening activity, there was no scarcity of spots during 1940, and some 25 groups reached or exceeded in area 500 millionths of the Sun’s hemisphere (a general lower limit for the naked-eye visibility of spots in the central region of the disk). Four of these groups exceeded 1000 units and are listed below with their times of central meridian passage and latitude:

(1) Jan. 5.5	10° N.	2500 millionths.
(2) Mar. 26.3	12° N.	1300 „
(3) July 7.6	18° N.	1050 „
(4) Aug. 20.9	9° N.	1200 „

No. 1, of rapid growth, reached 2500 millionths in area; the group returned on January 26–February 8 as two widely separated spots about 17° apart in longitude. The leader survived to a fourth transit of the disk. Group 2 was associated with a very disturbed terrestrial magnetic period from March 20 to April 2, when three “great” storms and two lesser ones occurred. A preliminary discussion of the associated phenomena—sunspots, bright chromospheric eruptions, ionospheric irruptions and magnetic storms—during this period is given in *The Observatory*, 63, 129, 1940. Other details of this active solar region will be found in *Journal B.A.A.*, 50, 246, 1940.

A succession of six large groups, with maximum area ranging from 500 to 1200 millionths, occurred in August and another of five groups in June. There appears, however, to have been a general absence of bright chromospheric eruptions of intensity as high as 3 on the international scale in association with these sequences of spot groups, and a corresponding general infrequency of ionospheric irruptions (producing fade-outs on short-wave long-distance wireless communication) may be noted.

During 1940 twenty magnetic storms were recorded at Abinger. Four of these storms were “great” storms in which the range in D was over 1° or that in H.F. or in V.F. was over 300 γ. The first three of these storms are referred to above. The fourth storm on June 25–26 occurred in association with the presence of two naked-eye groups in the central region of the Sun’s disk. No observation of a solar eruption of great intensity in association with these two groups has yet come to hand, nor yet of an ionospheric irruption.

H. W. NEWTON

Prominences.—During 1940 there has been on the whole a decrease in prominence activity although prominence areas have remained nearly steady and the numbers show a slight increase over the previous year.

The mean daily areas and numbers of calcium prominences as derived from Kodaikanal photographs are as follows:—

				<i>Areas</i>		
				North	South	Total
1940	January to June	...	...	2.48	2.55	5.03 sq. mins.
	July to December	...	...	2.40	2.60	5.00 „
				<i>Numbers</i>		
				North	South	Total
1940	January to June	...	...	7.43	6.87	14.30
	July to December	...	...	7.47	7.07	14.54

Compared with the previous year, there has been practically no change in prominence areas, but the numbers show an increase of 7 per cent. The areas and numbers are equally distributed in the northern and southern hemispheres. The distribution of areas in latitude shows that there are two zones of maximum activity in the northern hemisphere at latitudes 15° and 35° and one in the southern hemisphere near latitude 20° . The distribution of numbers is nearly uniform from the equator to latitude 55° .

Thirty-three metallic prominences were observed during 1940 as against 59 in the previous year. Of these, 15 were in the northern hemisphere and 18 in the southern, and all of them were observed from the equator to latitude 33° . Displacements of the hydrogen line in the chromosphere and prominences observed during the year with the spectroscope numbered 204 as against 451 in 1939. Of these, 112 were towards the red, 85 towards the violet and 7 both ways simultaneously. The largest displacement noticed was 9 A. to violet.

Bright reversals of the *Ha* line on the Sun's disc were observed with the spectroscope in the neighbourhood of sunspots on 744 occasions as against 963 in the previous year. The displacements observed in the neighbourhood of sunspots numbered 44 as against 64 during 1939. Of these, 29 were towards the red, 11 towards the violet and 4 both ways simultaneously. D_3 was observed as a dark line on 676 occasions as against 720 during the previous year.

The displacements observed in prominences with the spectrohelioscope numbered 124 as against 282 in the previous year. Of these, 49 were in the northern hemisphere and 75 in the southern, and 57 were on the east limb and 67 on the west limb. Displacements to the red numbered 67 and those to the violet 57. The largest displacement in the prominences observed during the year was 6.4 A. to violet.

Eruptive prominences on the limb were photographed on February 26, March 8 and May 29. The prominence of March 8 rose to a height of about $10'$ and that of May 29 showed maximum displacements of 6.4 A. to violet and 2.8 A. to red.

The mean daily area of prominences projected on the disc as hydrogen absorption markings was 7912 millionths of the Sun's visible hemisphere as against 9735 in 1939, showing a decrease of about 19 per cent. In the first half of the year its distribution in latitude is similar to that of prominences at the limb, with the peaks very much pronounced. But in the second half of the year its distribution, especially in the northern hemisphere, is irregular with a marked peak near latitude 15° .

A very large absorption marking, the largest for a number of years, was photographed during the first week of April. It extended almost from the east to the west limb on April 5 and 6 and its area was about 14,400 millionths of the Sun's visible hemisphere. The marking disappeared on April 8.

A. L. NARAYAN

DOUBLE STARS

New Pairs.—Kuiper gives some new binaries in *Ap. J.*, 91, 272, and 92, 126. Barton gives new double stars from the Paris Astrographic Catalogue (*A. J.*, 48, 145). Olivier has a note on the duplicity of B.D. $-3^{\circ} 579$ (*P.A.*, 48, 173) and Kopal a note on a new visual binary in *H.B.*, 911.

Measures.—*Flower Obs.*, vol. v, part ii, contains measures with the 18-inch refractor by Olivier, Barton and Wilson. Strand gives measures with the Leiden 10½-inch and photographic measures with the 13-inch (*B.A.N.*, 8, 339 and 349). Baize has continued his measures with the Paris 12-inch (*J.d.O.*, 22, 205, and 23, 49 and 56). Durny gives measures with an 11-inch (*J.d.O.*, 23, 20). *Bulletins* 1, 3, 4, 5 and 6 of the Carter Observatory, New Zealand, contain measures with a 9-inch refractor by Geddes and Thomsen. Renyl (*P.A.S.P.*, 52, 37) gives photographic measures of ADS 1104.

Orbits :—

ADS	Computer	<i>P</i>	<i>a</i>	<i>e</i>	Reference
3064	Wilson	7.2	0.144	0.00	<i>A. J.</i> , 49, 25.
4115	van den Bos	(linear formula)			<i>U.O.C.</i> , 102.
6175	Strand	380	5.941	0.359	<i>A. J.</i> , 49, 41.
6664	van den Bos	56.6	0.700	0.66	<i>U.O.C.</i> , 102.
9932	Wilson	55.0	0.483	0.88	<i>A. J.</i> , 49, 25.
14787	van Biesbroeck	49.80	0.85	0.24	<i>A. J.</i> , 48, 169.

Miscellaneous.—Russell and Moore have published a monograph "The Masses of the Stars, with a General Catalogue of Dynamical Parallaxes." Van de Kamp gives mass ratio and parallax of τ and 61 Cygni (*A. J.*, 48, 177; 49, 33) and a note on the proper motion of ADS 9982 (*A. J.*, 48, 176). Van de Kamp and de Vilbirs (*A. J.*, 49, 32) publish proper motions of some double stars, from plates taken with the 24-inch Sproul refractor. Kopal has a note on the triple system ADS 14787.

W. H. VAN DEN BOS

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Editors of *The Observatory*
Professor H. T. Stetson

In addition, the Society exchanges publications with about 250 institutions and observatories in most countries of the world; a full list of these is omitted, as in many cases difficulties of communication have led to suspension of exchange for the duration of the war.

ADDRESS

Delivered by the President, Professor H. C. Plummer, on The Development of the Vertical Telescope

For the first time for many years it has appeared to the Council inexpedient to award the Gold Medal of the Society. To justify this decision it is not difficult to find a good and sufficient reason. The value of the award from year to year depends in a large measure on one condition, that the choice is world-wide and free from bias. Can that freedom be said to exist to-day? Even though our impartiality were above suspicion, freedom of communication with many countries has been lost. In these circumstances the Fellows will understand the action of Council in making no grant of the Medal.

Since there is no Medallist, your President cannot make his work the text of a presidential address. Whether there shall be a George Darwin Lecture later in the year is an independent question, which will be carefully considered. In the meantime a retiring President might be allowed to fold his tent "like the Arabs, and as silently steal away." But it has been represented to me that even in these sombre days an address is expected. It is a tradition, and as such it is not to be lightly disturbed by passing events however grave. Therefore it only remains to choose a subject, and for that we may recall some of those events which have occurred in the development of modern astronomical instruments, and especially in the evolution of that extremely interesting form, the tower telescope.

In the article on Telescopes which he contributed to the *Encyclopædia Britannica* * early in the present century, Sir David Gill distinguishes no less than six types of equatorial. The number seems excessive. We admit readily enough the English mounting, the German mounting, and perhaps as a more or less natural development from the primitive forms the equatorial coudé. But how is this small number to be doubled? In the first place by distinguishing two forms of English mounting according as the telescope is mounted centrally within the polar axis, or externally on one side of this axis with a counterpoise on the opposite side. This is a difference of detail in design rather than of principle. Then there is the cradle or forked pattern, which is appropriate to the reflector and not to the refractor. In this case a distinct type may be admitted. But a sixth type is still to seek, and this takes the form of a fixed telescope used in conjunction with a mirror system. It is to be observed that the article was written before the first tower telescope was erected on Mount Wilson, probably before it was even contemplated. But with all deference to so high an authority as Sir David Gill, this extension of the term equatorial is surely too wide to be convenient. The point has been reached when a common purpose is no argument for confusing the means by which the object is attained. The equatorial may be defined as a telescope mounted in such a way as to provide independent motions in declination and in hour-angle, and in common practice the latter motion can be maintained by a driving clock or equivalent mechanism. So defined it cannot be confused with a fixed telescope which is enabled to perform its function by the provision of appropriate optical accessories. The whole history of the two forms is different. The equatorial coudé is an intermediate instrument, and as such, from the point of view of classification, occupies a slightly dubious position.

When Newton submitted his reflecting telescope to the Royal Society at the end of 1671, it met with such a flattering reception that he was encouraged to communicate the results of his experiments on dispersion and the nature of light and colours. But a hard disappointment was in store, for criticism came from three distinct directions. It was

* 11th edition.

not in Hooke's nature to welcome an intruder in a province which he considered peculiarly his own. More serious from an historical point of view were the objections which came from the Cartesian school of philosophy, for they were incidents in an unequal battle of fundamental ideas in which Newton was destined to gain an effortless victory. But the third line of criticism, which came from Liège, was genuine scientific comment. It came from men who honestly tried to repeat Newton's experiment and failed to reproduce his first result exactly. The discordance was really important, and the reason for it can be easily conjectured. At that time the prevailing type of glass manufactured in England was flint. Equally the common type of continental glass was crown. It is therefore not surprising that the Belgian prism had a lower dispersive power than Newton's and produced a shorter spectrum. Here was a difference of the utmost practical importance. Unfortunately, as Locke afterwards wrote of him, "he is a nice man to deal with, and a little too apt to raise in himself suspicions where there is no ground." And so Newton, while claiming *hypotheses non fingo* and in the face of positive evidence, committed himself to a fateful assumption. The belief that glass is glass and that no combination could solve the problem of achromatism persisted through a century until Euler and Dollond attacked the dogma. Even Huygens accepted it, and saw the only hope of better telescopes in improved methods of glass manufacture and lenses of longer focal length. As an example of the resulting type of instrument we may recall the zenith telescope with which Bradley discovered the effect of aberration, to the enrichment of astronomy and the serious damage to his aunt Pound's house at Wanstead.

Such was the practical effect of the failure to pay any attention to the candid efforts of Linus and Lucas to repeat Newton's work on dispersion. The larger telescopes of the eighteenth century were unsuitable for mounting equatorially or in any convenient manner whatever. During the same period reflecting telescopes failed to make the progress which had been anticipated for them. When at length they came into their rightful position with William Herschel, they quickly assumed a size which presented as great a problem as the inordinately long refractors of the earlier generation. Neither the large reflector of Herschel nor the still larger mirror of Lord Rosse was provided with a reasonably convenient form of mounting. Indeed, the design of efficient equatorials for really large mirrors is an achievement reserved for the present century.

In the meantime the typical large-scale instrument of the nineteenth century was the visual refractor with the German form of equatorial mounting which originated with Fraunhofer (1787-1826). With the advantage of achromatic lenses his telescopes were small, 7 or 8 inches in aperture, but in the following years as the size increased the same pattern in all essentials was followed until the type culminated in those superb instruments, the Lick 36-inch and the Yerkes 40-inch. Perhaps naturally it became usual to extol this type of mounting unreservedly and to ignore the fact that the general type covered many examples of extremely bad design. Even apart from avoidable weakness in construction, as other functions were added to an instrument originally designed for visual observation only, the merits of the English mounting became more widely appreciated. At the Liverpool Observatory there is an equatorial in which a small 8-inch telescope is mounted between large boiler plates which form the polar axis. The disproportion in size gives the whole instrument a rather absurd appearance, altogether lacking the æsthetic attraction of the German form. Yet I remember the enthusiasm with which the late Dr. Max Wolf devoted a Sunday afternoon in the late nineties to the minute examination of the mechanical construction of this, to him, strange instrument.

But our concern is not with such instruments, even in such an impressive form as the Greenwich 28-inch. Only in passing we notice the limitations of a design which a hundred years ago seemed to satisfy all the general requirements of astronomy. But earlier, before the possibility of achromatic lenses had been realized and when telescopes

were in consequence of unmanageable length, it must have been evident that the problem must be attacked in a different way. Nor was the advantage of using a telescope in a fixed position overlooked. In fact the earliest suggestions for achieving this object in a practical way have been credited to no less than four men*: Hooke, Halley, Roger Cotes and Fahrenheit. The most obvious direction for the axis of the telescope is the polar axis, and that suggested the simplest solution of the problem. But experiments of the kind initiated by Newton, to which reference has already been made, must have shown the inconvenience caused by the diurnal motion of the Sun and suggested the advantage of using a horizontal beam. This constitutes the general problem of the heliostat, the first solution of which was reserved for s'Gravesande.

At the present time not all the original sources of information are open to reference. That matters the less because the early descriptions of a polar heliostat never seem to

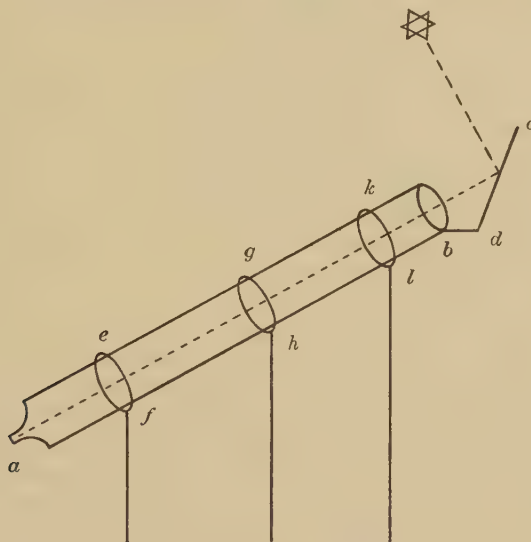


FIG. 1.—Cotes' Telescope.

have advanced beyond the stage of mere suggestion. The device proposed by Cotes is probably typical, and as it does not seem to be familiar his words may be quoted. They occur in a letter† written from Cambridge to his uncle, the Rev. John Smith, under date Febr. 10, 1708 (O.S.).

... "I have lately hit upon a contrivance which I beleive will be of very good use for observing Eclipses. You will easily understand it by this rude draught. The Telescope *ab* is to be so directed as to look at y^e Pole of y^e World & thereby its axis will be parallel to y^e Axis of y^e Earth in which position it must be fixd by y^e rings *ef gh kl*. *cd* is a looking glass reflecting y^e Object into the Telescope. Then if y^e Telescope revolve about its Axis within the rings with a motion correspondent to that of y^e Earth about its Axis the Object will constantly be in y^e Telescope for a whole day together as You will easily understand by considering y^t y^e looking Glass participates of y^e same uniform motion by being fixt to y^e Tube. I have not described y^e method of altering y^e Inclination of y^e glass according to y^e different Declination of y^e Object from y^e Aequator. You will easily find out how y^t may be done as also how a piece of Clock work if it be thought needfull may communicate to y^e Telescope its due motion about its Axis . . ."

Reverse the order of the mirror and the object-glass, and invert the direction of the whole instrument, and the affinity with the Cambridge equatorial coudé is easily seen.

* In addition to Boffat, *J. des Sçavants* (1682).

† Edleston, *Correspondence*, p. 198.

It was one thing to allude to a "looking glass", it was quite another for the technique of the day to provide a plane mirror with the requisite optical perfection and reflecting power. Equally to speak of a "piece of clock work" is not the same thing as making a satisfactory driving clock, though this device had been suggested by the versatile Hooke years before. It does not appear that this or any other form of polar heliostat has ever assumed a practical shape.

The first solution of the general problem of the heliostat was given by s'Gravesande (1688-1742), and the description is contained in the third edition (1742) of his *Physices elementa mathematica* . . . *Sive Introductio ad philosophiam Newtonianam*." This work was translated by Desaguliers and thereby the word "heliostate" came into our language. But if any instrument of this type was made in the eighteenth century it had no astronomical application in the general sense.

The first trace of the solar spectrum was seen by Wollaston in 1802. Twelve years later the systematic study of this spectrum begins with the work of Fraunhofer. From this time onward the heliostat became an indispensable accessory of the physical laboratory. Stimulated by this need, new designs, variants of the original pattern proposed by s'Gravesande, were brought forward. It is interesting to notice that all these developments have emanated from one country, France. After Gambey (1831) and Silbermann (1844), Foucault designed yet another form in the last year of his life (1869). It is at this point that the term "siderostat" first appears. But more than a change of name was needed to extend the function of an instrument which served well enough its primitive purpose of deflecting a beam of sunlight in a given direction.

At last a really large telescope was constructed, to be placed in a horizontal position and fed by a siderostat after Foucault's design. The combination was shown at the Paris Exhibition of 1900. Unfortunately no adequate report seems to have been published of its performance in ordinary astronomical use. This is greatly to be regretted since the experience is not likely to be repeated. It will probably be agreed that in none of the designs hitherto produced has the heliostat satisfied the exacting mechanical conditions required in a large-scale astronomical instrument.

There is one property of the heliostat to which up to this time no particular attention seems to have been directed. This is the rotation of the field, which is immaterial when only a beam of sunlight is required, but which becomes important when a field of stars is to be photographed. In the case of the polar heliostat it is obvious that the field rotates uniformly in 24 hours. In other cases the period remains the same, but the rotation is no longer uniform. The nature of this rotation was discussed* by Cornu, who noticed that it is of the kind produced by a Hooke's joint. This suggested a simple way by which the motion of the field can be compensated, and different methods were proposed by Turner and one by myself. But though a simple device is possible, this adds a further complication to an instrument already too complicated for practical application in its general form. But already, in 1895, the brilliant French physicist, Gabriel Lippmann†, had pointed out the advantages offered by the most effective particular case of the instrument and given it the appropriate name of Cœlostat. It was at least the fourth time that this special form had been made known since what seems to have been its original discovery by August in 1839. But Lippmann was more than a godfather. He seems to have been the first to realize the importance of the stationary field. As we have seen, the rotation of the field of the siderostat was first seriously investigated by Cornu in 1900. If the matter had been given a thought, for the purpose of the heliostat had hardly required it, it would naturally be supposed that a diurnal rotation according to some law was common to all forms of the instrument. In fact the apparent exception does present a curious paradox, which can be readily explained by the analogy with Hooke's joint. Thus if *A, B* represent on a sphere the

* *Ap. J.*, 11, 148, 1900.

† *C.R.*, 120, 1015, 1895; *Observatory*, 18, 301, 1895.

direction of the two arms of the joint, let $CAP = CP = \frac{1}{2}h$ and $CBP = \frac{1}{2}\theta$ measure corresponding rotations of these arms.

Then if $AB = \alpha$, $AC = AP = 90^\circ$, $\tan \frac{1}{2}\theta = \sec \alpha \tan \frac{1}{2}h$, so that these angles are related in the same way as the heliostat imposes when h is the hour-angle of the object from the instrumental meridian and θ the corresponding orientation of the field. When B coincides with A , BP rotates uniformly with AP ; it is the case of the polar heliostat. As B is displaced towards C , $\frac{1}{2}\theta$ changes with $\frac{1}{2}h$ from -90° to $+90^\circ$ but not uniformly, the motion being most rapid in the neighbourhood of C . Finally, when B coincides with C , $\frac{1}{2}\theta$ changes instantaneously through 180° at C . But this means that θ changes through 360° , and this is no change of direction at all. It is the case of the cœlostat.

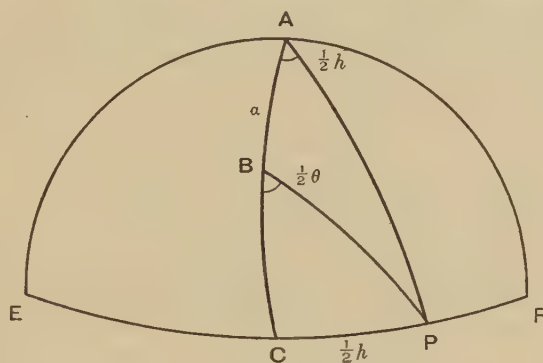


FIG. 2.—Field Rotation.

It is commonly said that the cœlostat mirror rotates uniformly once in 48 hours. This is not strictly true, for clearly the rotation must be completed in 24 hours. In reality the mirror rotates uniformly through 180° in 24 hours and passes instantaneously through the remaining 180° ; reflexion from the back of the mirror is not contemplated.

For the stationary field a price must of course be paid. The fixed reflected ray is directed to a declination opposite to that of the object, and therefore if the telescope is horizontal its azimuth is determined by the declination of the object. A circumpolar object cannot be reflected in a horizontal direction at all.

If Lippmann's description of the cœlostat had nothing novel to recommend it, his publication of it in 1895 was none the less justified by the event. At last the merits of the instrument were recognized by the Eclipse Committee and it was immediately adopted. A cœlostat was designed by Common and constructed in time for Turner to take it, after preliminary trials, to the Japanese eclipse of August 1896. Further experience was gained by Turner at the Indian eclipse early in 1898. From that time onward the position of the cœlostat has been established as standard equipment of an eclipse expedition. This is its most natural application, and the casual reference by Cotes to eclipse observations as the appropriate purpose of his polar telescope and mirror seems strangely prophetic.

Among the earliest attempts to widen the scope of the cœlostat the work of Mr. J. H. Reynolds early in the century deserves to be recalled. He had made a 24-inch reflector and a 30-inch plane mirror. For photographic purposes the reflector was mounted as a horizontal telescope, and, in order to reduce the necessity for frequent changes in azimuth, the cœlostat mounting of the flat was so far modified that the normal of the mirror could be turned out of the equatorial plane and the rate of driving could be adjusted. This produced the simplest form of an instrument which has since been constructed for the Bergedorf Observatory and dignified with the name of Uranostat. Mr. Reynolds published a brief description* only in 1908, but he had practically

* *M.N.*, 68, 488, 1908.

explored these instrumental possibilities several years before. As I have been credited with being the first writer on the theory of the Uranostat, it is only right to mention that my paper * on the subject in 1905 was entirely prompted by a knowledge of what Mr. Reynolds had done.

The conclusion to which he was led by practical experience was that the possibilities presented by this instrumental arrangement were distinctly limited, though some results of value were obtained, particularly in the domain of planetary photography. Theory could point out the more favourable conditions, but it could find no prospect of securing really prolonged exposures: departure from the conditions of the cœlostat must soon prove fatal to a satisfactory result. After a few years Mr. Reynolds abandoned this line of experiment and turned his attention in another direction. For this two very good reasons may be guessed. In making two mirrors of considerable size with his own hands he had done all that could be expected of a private individual. Furthermore, as his interest was changing to nebular research, it was clear that the multiplication of reflecting surfaces was the last thing to be contemplated lightly. The fact remains that this work of Mr. Reynolds represents the earliest attempt to apply the principle of the cœlostat to astronomical objects beyond the field of solar research.

But about the same time as Mr. Reynolds was beginning his experiments the cœlostat was being applied in circumstances which did not necessitate the same economy either in material resources or in light. The incentive came from the requirements of the spectroheliograph. This instrument can be designed for use in conjunction with a large equatorial, as the Rumford spectroheliograph mounted on the Yerkes refractor has proved. But the earlier trials showed that this combination was not free from difficulties in manipulation. The power of even an exceptionally large equatorial is severely strained, and a horizontal motion in a fixed position is far better suited to the spectroheliograph. Here in fact was a clear opportunity for the cœlostat used with a reflector to send the solar image in a horizontal direction. But then the changing declination of the Sun entails the inconvenient consequence of a changing azimuth. This difficulty Hale overcame in the simplest possible manner by introducing a secondary adjustable plane mirror to divert the solar beam from the cœlostat in the direction of the reflector. The result was the Snow telescope, the horizontal telescope which has a splendid record of work to its credit.

It is not, however, on the excellences of this instrument that we need to dwell. On the contrary, the more important fact is the imperfect definition which was obtained from the arrangement in all but the most favourable conditions. Between the cœlostat and the image the beam traverses twice over a louvred structure designed to protect the air in front of the concave mirror from the direct heat of the Sun. The means taken with this object were never entirely successful. Convection currents at right angles to the axis of the telescope disturbed the definition, and stirring the air by electric fans provided only a partial remedy. To obtain the most satisfactory results with the spectroheliograph, work was limited to the early morning and the late afternoon. The astronomers of Mount Wilson were exigent, and the exacting demands of solar research must be met at all hours of the day. The horizontal telescope had not completely solved the problem and Hale was looking further ahead.

It was my privilege at the Oxford University Observatory to have an early view of these developments. The cœlostat was a familiar instrument, for Turner had been the first to demonstrate its utility in eclipse work. Then Mr. Reynolds had combined it with a horizontal telescope for more general photographic purposes, and his experience had revealed the inconvenience arising from a change in azimuth and the difficulty of avoiding it. This obstacle was overcome in the Snow telescope by the introduction of the secondary mirror, which is easily manipulated when the object is the Sun. But this additional mirror, once introduced in order to avoid constant changes of azimuth

* *M.N.*, 65, 487, 1905.

in the horizontal plane, obviously presented much wider possibilities. Any fixed direction could be chosen, and it was natural to examine the vertical position in particular. Immediately two advantages became apparent. Vertical atmospheric currents coinciding with the axis of the telescope would be far less harmful than lateral currents transverse to the axis as in the Snow telescope. In the second place, the benefit of a steady temperature could be secured by placing part of the apparatus underground. This was a consideration of greater importance for mirrors in days when Pyrex glass was unknown. The purpose in view did not go beyond the aim pursued by Mr. Reynolds, simple astronomical photography, but it was realized that once the image was produced in a convenient position near the surface of the ground it could be investigated in a variety of ways.

It may now be permitted to recall the rough sketch which was shown in this room exactly thirty-six years ago. It is hardly likely that this crude idea had any influence

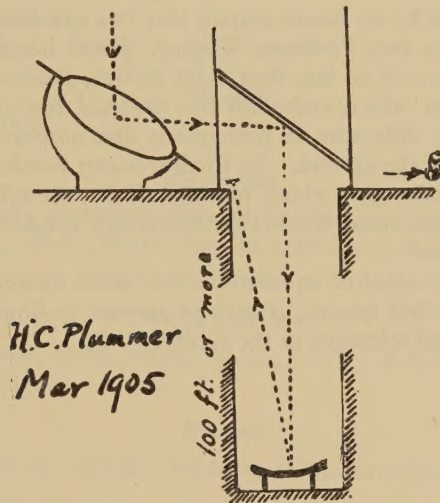


FIG. 3.

on the design which took a material form some two years later in the first tower telescope on Mount Wilson, though Hale made a generous reference to it. Yet the first tower telescope met with such outstanding success, in which it has been followed by others of a like type, that an intelligent anticipation of the principle may still claim a certain interest. The tower and the substitution of a long-focus refractor for the reflector are due to the genius of Hale, aided by suggestions from Dr. C. G. Abbott. These are features not likely to occur to a modest English astronomer to whom it is never given to command considerable financial resources. Thus under the pressure of economy the nearest approach to the original suggestion is to be seen in the vertical telescope at Oxford, designed by Professor Plaskett. It may be hoped that in happier times this installation, the only one of its kind in this country, will give him every satisfaction.

Modern developments of the tower telescope are within recent memory and need not be followed further. These instruments serve the essential purpose of using a telescope of long focal length to produce a large-scale solar image of the best attainable quality. They have therefore rendered conspicuous service in the cause of solar research. As an indispensable element in making this possible the *cœlost*at has found a field of daily application. But in the wider range of astronomy it must be admitted in retrospect that this instrument has proved relatively ineffective. For this the reason is not perhaps very difficult to see. Apart from the exceptional conditions of an eclipse

expedition, the main function of the cœlostæt is to facilitate the use of long-focus instruments. Now the instrumental developments of the present century have followed two main lines. While the vertical telescope has served the needs of solar research, other purposes have called into existence the Cassegrain reflector equatorially mounted. In the search for light-gathering power the latter has increased greatly in size and the limit has not been reached. Of the prospects before that type of instrument, with its greater resolving power and capacity to plumb the depths of space, it is unnecessary to speak. The one property of the Cassegrain telescope which is relevant to the present line of thought is the production of a large-scale image with no corresponding increase in the length of the telescope. Owing to this power, the limits of which have probably not been fully explored as yet, the need for long telescopes in a fixed position no longer exists, and, as far as can be seen at present, the cœlostæt is unlikely to find any useful scope in stellar astronomy. It will continue to prove itself an indispensable adjunct in the service of the Sun.

At the same time it is by no means certain that this conclusion will ultimately prove to be the right one. In fact Professor Ritchey, whose imagination has soared to a telescope with an aperture of no less than eight metres, produced in 1929 an elaborate design for an instrument which embodies the essential features of the sketch shown here in 1905. The only difference in principle is that no part of the structure is submerged below the level of the ground. In Ritchey's own words: "The Fixed Universal reflector is the *only known type* which permits all known refinements to be utilized simultaneously, under the most favourable laboratory conditions, and to the utmost limit of their possibilities."

We may not be within sight of an instrument of these mammoth dimensions, but, in view of an opinion like that quoted, it may be unwise to limit the possibilities which may lie before the vertical telescope of the future.

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